NAVAL HEALTH RESEARCH CENTER

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NAVAL MEDICAL RESEARCH AND DEVELOPMENT COMMAND
BETHESDA, MARYLAND

Evaluation of the Efficiency of Microclimate Cooling in a Hot Weather CBR Environment

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SUMMARY

Problem:

The threat of chemical warfare associated with the war in the Persian Gulf revealed that insufficient information is available regarding the unique environments of Navy/Marine Corps personnel who can be exposed to both high humidity/head loads and chemical/biological attack. Dissipation of heat is a problem for personnel encapsulated inside chemical, biological, radiological (CBR) ensembles. The CBR clothing prevents noxious agents from reaching the skin; however, due to the low-moisture permeability and high-insulating properties of CBR clothing, heat generated metabolically or gained from the environment is prevented from dissipating. Impairment of heat dissipation can result in heat injury ranging in severity from discomfort to performance decrements, illness (cramps, exhaustion, stroke), collapse, and even death. Microclimate cooling thus becomes essential for prevention of heat strain, and ideally, maintenance of thermal balance in hot (and noxious) environments. This study was designed to determine the effectiveness of microclimate water-cooling for personnel encapsulated in CBR who were required to perform intermittent exercise.

Objective:

The primary objective of this study was to determine the effectiveness of whole-body cooling to prolong stay time for subjects who were exercising on an intermittent basis. Another objective was to determine if doubling the flow rate of the cooling fluid enhanced heat dissipation (225 versus 450 ml/min).

Approach:

Six unacclimated male subjects, who were clad in a standard Navy work uniform and a CBR suit, walked on a treadmill at 3 mph and 2% grade in a hot environment (ambient temperature = 100°F). The subjects repeated the test under three conditions: a control test when no cooling was provided, an experimental test when intermediate cooling was provided (flow rate = 255 ml/min, water temperature = 55°F), and an experimental test when maximal cooling was provided (flow rate = 450 ml/min, water temperature = 55°F). The subjects alternated 50 min of exercise with 10 min of rest for a maximum of 2 hr. The physiological measurements

recorded included: rectal, skin, and tympanic temperatures, electrocardiogram, heart rate, blood pressure, minute ventilation, oxygen consumption, urine production, and body weight loss.

<u>Results:</u>

Microclimate cooling significantly extended the time the subjects could exercise (107 versus 120 min). Early termination of the experimental protocol, in 5 out of the 6 subjects, occurred when no cooling was provided. When cooling was provided all the subjects completed the 2-hr test. During the first hour of the test, there was no significant difference in heart rate or rectal temperature between the control and experimental tests. The effectiveness of the microclimate cooling system was seen during the second hour of the tests. At 90 min, tympanic temperature and heart rate were significantly greater in the control versus cooling condition. Additionally at 90 min, rectal temperature was significantly higher in the no cooling versus maximal cooling test. At 50 and 90 min, there was no difference in heart rate, tympanic, or rectal temperatures between the intermediate and maximal cooling conditions. In both the intermediate and maximal cooling tests, body water loss was significantly less when compared to the control test.

<u>Conclusion:</u>

This physiological study demonstrated that whole-body microclimate cooling significantly lengthened the time subjects could exercise in a hot environment. When compared to the control test, microclimate cooling reduced the core temperature rise and significantly reduced cardiovascular drift during the second hour of the test. Use of this water-cooling device decreased body weight loss attributed to sweating. The use of higher water flow rates did not significantly extend stay time, nor effect heart rate, rectal, or tympanic temperatures.

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INTRODUCTION

The purpose of this project is to evaluate the efficiency of a microclimate cooling system (Flexitherm vest and cap, Life Support Systems Inc., in conjunction with a thermoelectric cooling/heating unit, Carlson Technology Inc.), when worn under a chemical protection garment (Chemical and Biological Protection Suit, Carbon Sphere #8415-01-333-7578) and tested in an ambient temperature of 37.8°C (100°F) with subjects performing moderate exercise (walking at 3 mph at 2% grade).

MATERIALS AND METHODS

Experimental Protocols: Three experimental protocols (conditions) were employed.

a. Control:

Subjects were dressed as described below, performed moderate exercise (treadmill walking at 3 mph at a 2% grade), but no cooling was initiated.

b. Intermediate Cooling:

Subjects were dressed as described below, and performed moderate exercise. Cooling was initiated at the start of the exercise and continued throughout the experiment. Cooling fluid was delivered to the vest and cap at a rate of 225 ml/min with an input temperature of 12°C (55°F).

c. Maximum Cooling:

Subjects were dressed as described below and performed moderate exercise. Cooling was initiated at the start of the exercise and continued throughout the experiment. Cooling fluid was delivered to the vest and cap at a rate of 450 ml/min with an input temperature of 12°C (55°F).

Subject Selection and Screening:

Prior to selection and screening of subjects for this project, all experimental protocols were reviewed and approved by the University of Minnesota Committee on the Use of Human Subjects in Research.

Screening of the subjects included the following: (1) body fat determination by underwater weighing (Brozek, 1963) -- acceptable range, not less than 10% nor greater than 20% body fat, (2) 12 lead electrocardiogram interpreted as normal by a member of the Clinical Sciences Department of the University of Minnesota, Duluth School of Medicine, and (3) an exercise test consisting of walking at 3 mph starting at 2% grade and increasing at 2% grade intervals up to 18% grade (modified Balke, 1986). Acceptable limits for this exercise test were a heart rate that did not exceed 90% of age predicted maximum, systolic blood pressure that did not exceed 200 mmHg, and diastolic blood pressure that did not exceed 100 mmHg.

Subjects that met all of the above criteria were briefed on the experimental protocol and read and signed the informed consent document.

Since the protocols to be used in this project would require the subjects to wear equipment which is not only unfamiliar to them but somewhat confining, each subject reported to the laboratory prior to the day of the first experiment for an orientation session. This orientation involved wearing the clothing, the cooling system, and the chemical protection system and walking on the treadmill for 5 to 10 min. This was designed to minimize the stress of the unfamiliar situation during the first experiment.

The subjects were given instructions to follow the day prior to each experiment (see below). This included a hydration protocol to assure that all subjects were at approximately the same hydration level at the start of each experiment. Subjects were scheduled to complete the experiment at approximately the same time of day for all three conditions. For each subject at least a week elapsed between experiments.

Preexperiment Instructions

1. Drink 8-16 oz. glasses of water, about 1 every 2 hr the day prior to the experiment.
2. No drugs, alcohol, or tobacco 24 hr prior to the experiment.
3. No caffeine on the day of the experiment.
4. Eat a moderate meal prior to the experiment.
5. Get a normal night's sleep the night prior to the experiment.

Clothing:

Clothing ensemble: For each of the test protocols the subjects were clothed as follows:

1) underclothes--cotton T shirt, boxer shorts, and socks (Figure Ia).
2) uniform--long sleeved cotton/polyester shirt and cotton pants (Figure Ib).
3) microclimate cooling equipment--consisting of a vest and cap (Flexitherm vest and cap, Life Support Systems Inc., in conjunction with a thermoelectric cooling/heating unit, Carlson Technology Inc.) worn over the uniform (Figure Ib).
4) chemical protection suit (CBR CS#8415-01-333-7578)--consisting of pants and jacket--were worn over the clothing listed in 1 through 3.
5) gas mask (MSA91J012-013)--was worn over the cap portion of the microclimate cooling system. Care was taken to tighten the mask to allow it to function properly but not impede the flow of coolant to the cap. The gas mask was modified to allow for the measurement of ventilatory parameters (tidal volume, respiratory rate, oxygen consumption, and carbon dioxide production, see Figure Ic & d).
6) footwear--tennis shoes
7) hands--no gloves

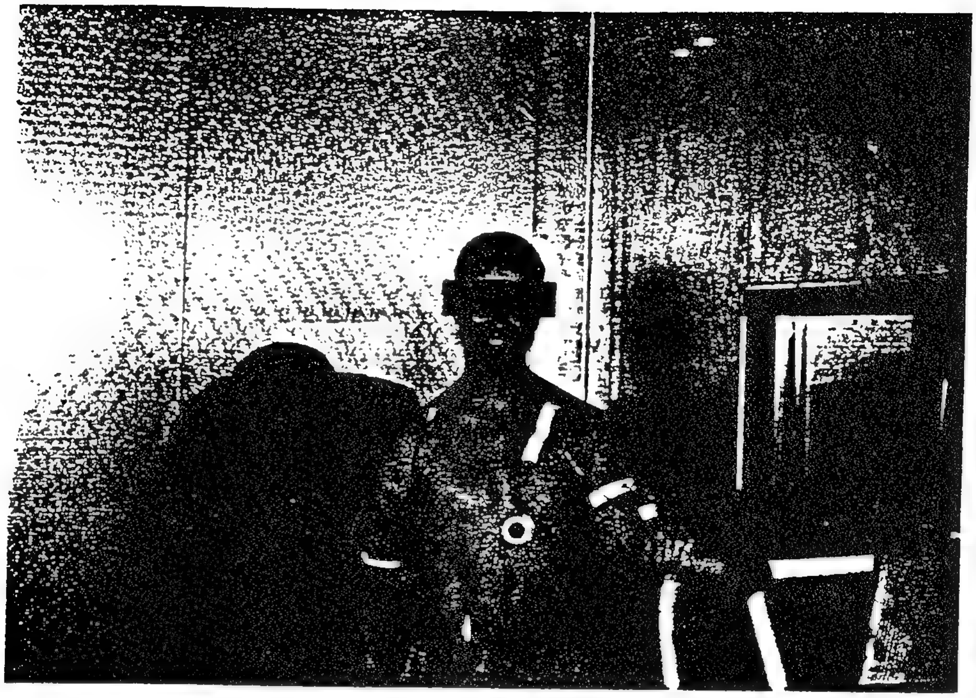


FIGURE I- a

Subject after application of skin temperature probes, electrocardiogram leads and blood pressure cuff.

FIGURE I- b

Subject wearing uniform and microclimate cooling vest.

FIGURE I- c

Subject dressed in full chemical protection suit and gas mask.

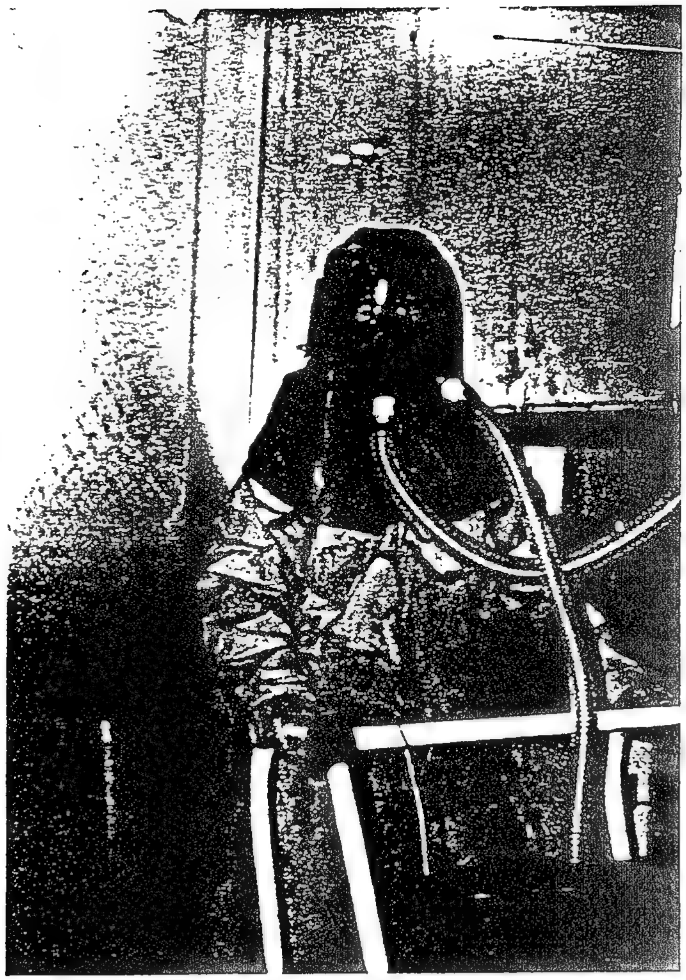


FIGURE I- d

Subject walking on the treadmill. Gas mask is connected to plastic tubing for respiratory measurements. Note: that the inspired air is drawn through the canister, the air supply come from inside the chamber.

Subject Instrumentation:

Upon arrival the subject was given a rectal probe and a vial for collection of a urine sample. The subject inserted the rectal probe a minimum of 8 cm past the anus and provided a urine sample with the time of the previous voiding so that a pretest urine flow could be calculated.

The remainder of the instrumentation was done in the environmental chamber (temperature - 80°F). The subject, dressed only in shorts, was weighed and the following electrodes attached:

1. ECG electrodes (2 sets) set in modified lead-2 configuration. One set was monitored by telemetry and the other directly wired to a recorder as a backup system (see Figure Ia).
2. Temperature and heat flow probes.
   a. lateral upper arm
   b. chest, above medial end of left clavicle
   c. medial mid thigh
   d. medial mid calf
   e. back, at the inferior angle of the scapula
3. Pants and shirt were donned.
4. Blood pressure cuff placed on right arm. Blood pressure was monitored with a semiautomatic system (Omron Automatic Blood Pressure Monitor - HEM-703-CP, Omron Marshall Products Inc., Lincolnshire, IL). The subjects straddled the treadmill belt during the blood pressure measurement (measurements of blood pressure were taken every 15 min).

5. Donned the microclimate cooling system.

6. Additional temperature sensors were placed in the following locations.

   a. top of head (inside cap)

   b. chest-#2 (between vest & chem suit) same location as skin sensor

   c. back-#2 (between vest & chem suit) same location as back skin sensor

   d. head-#2 (between cooling cap & gas mask cowl) same location as (a) above.

7. Donned the chemical defense suit. Temperature sensor placed on back (same location as back skin probe) outside of chemical protection suit.

8. Donned gas mask and cowl.

9. The heating of the chamber was initiated (approximately 10 min was required for the chamber to reach 37.8°C (100°F).

10. Control measurements were taken while the chamber warmed up.

11. At time zero the subject began walking on the treadmill (speed = 3 mph, grade = 2%). In protocols b and c (see Introduction) cooling of the subject was initiated at this point. The exercise period continued for 50 min, followed by 10 min of rest (sitting) and a second exercise period of 50 min followed by 10 min of rest (sitting).

12. At the termination of the experiment the subject was undressed, weighed, and provided a urine sample.

Urine Analysis:

Urine volumes and voiding times were recorded. Specific gravity was determined with a hydrometer and a routine dip stick analysis was performed to screen for any abnormalities.

Data Acquisition:

Temperatures, heat flows, electrocardiogram, and respiratory parameters were monitored continuously employing an A/D converter and LabVIEW software (National Inst., Austin, TX) driven by a Macintosh Quadra 950 computer (Apple Inc., Cupertino, CA). The digitized data, acquired at 10 Hz, was averaged and logged at 1-min intervals. Optical tympanic temperature (FirstTemp, IMS Intelligent Medical Systems, Paseo Del Lago, CA) was measured at 5-min intervals through a flap cut in the side of the gas mask cowl. Blood pressure (systolic and diastolic) was taken at 15-min intervals.

Statistical Analysis:

Data were analyzed with a one-way analysis of variance employing the Statistical Package for the Social Sciences (SPSS) on a Macintosh computer (Apple Inc., Cupertino, CA). For a comparison to be considered as significantly different, a $p < 0.05$ must have been obtained.

Cooling Methodology:

The system employed to provide the cooling liquid for the vest and cap consisted of two parts: (1) a thermoelectric unit that acted as the primary cooling source, and (2) an ice water bath. The ice water bath system was connected in parallel with the thermoelectric unit and was only activated when the thermoelectric unit could not provide sufficient cooling to maintain input temperature to the microclimate cooling apparatus at the preset level.

In order to monitor the functions of the cooling system, the following parameters were measured: (a) volume flow through the system, (b) the input and output pressure to and from the cooling vest-cap, and (c) the input and output temperatures to and from the vest-cap. The quantity of ice used in the secondary cooling system was measured in order to estimate how much additional cooling was needed to supplement the thermoelectric unit. See Figure II for a diagrammatic representation of the cooling system.

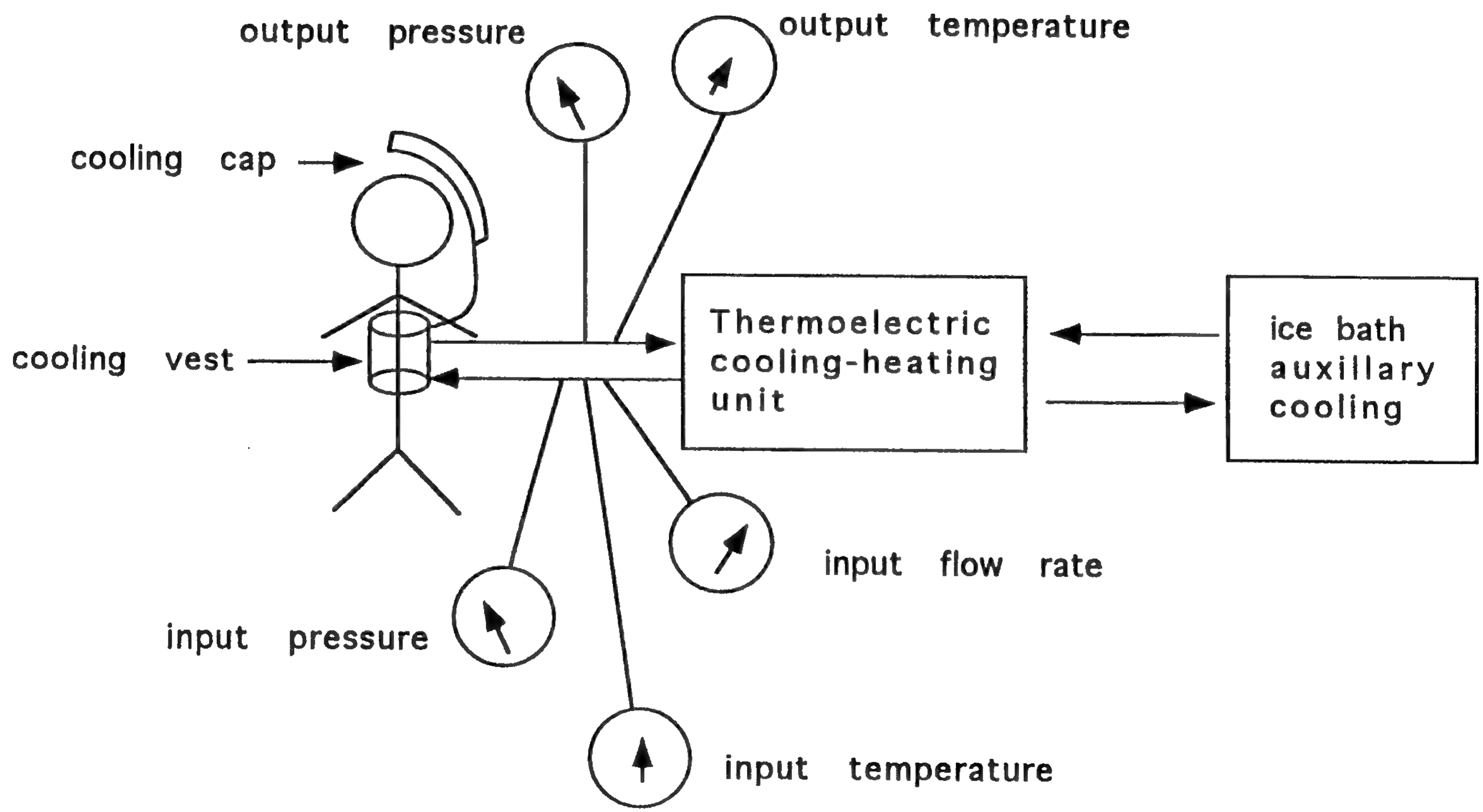
Early Termination of Protocols:

A protocol could be terminated by the subject at any time without their providing a reason. Criteria for termination of the protocol by the experimental team were as follows:

1. If the subject's rectal temperature reached 39°C.
2. If the subject's tympanic temperature reached 39.5°C.
3. If the subject's heart rate reached 80% of predicted maximum and stayed at that level for 20 min.
4. If the subject's heart rate reached 85% of predicted maximum.
5. If the subject's systolic blood pressure reached 200 mmHg.
6. If the subject's diastolic blood pressure reached 100 mmHg.
7. If the subject's ECG showed any abnormalities.
8. If equipment problems jeopardized the safety of the subject or the reliability of the data.
9. If the subject reported unusual symptoms, e.g., dizziness, nausea, extreme fatigue.

Figure II

Arrangement of cooling system, indicating monitored parameters.



RESULTS

Table I summarizes the characteristics of the subject population (age, height, weight, etc.). Early termination of the experimental protocol (5 out of the 6 subjects) occurred only in the control condition (no cooling). The criteria used to terminate these experiments were 1, 2, 3, 4 & 9 (early termination of protocol). In this group of experiments (no cooling), the mean termination time was 107 min with a range from 100 min to 120 min. Table II indicates the termination criteria for each subject as well as the ending values for the "primary parameters" (core temperature and heart rate). After early termination in the control condition, subjects were monitored for 10 min under nonexercising conditions.

Temperature Parameters:

Time dependent changes in rectal temperature for each individual subject and for the three experimental conditions are presented in Figures III (a-f). For purposes of identification, the protocols are identified by the flow rate of cooling solution delivered to the vest and cap: 0 flow = no cooling, 225 ml/min = intermediate cooling, and 450 ml/min = maximum cooling. Data analysis was done between 0 and 90 min during which parameters were available for all 6 subjects; the 90-min point was the earliest time at which a control experiment was terminated. Figure IV is the plot of the mean rectal temperature of the 6 subjects for the three conditions. During the first 50 min of exercise there is no difference in rectal temperatures between the three protocols. At the rest point (50 to 60 min into the experiment) the rectal temperatures in the non-cooled condition are higher than those of either of the cooled conditions, and these continue to increase and diverge from the cooled conditions. With respect to the two conditions that received microclimate cooling, there was no significant difference in rectal temperature between the conditions with a cooling rate of 225 ml/min and with a cooling rate of 450 ml/min (see Figure IV).

Table I.

Description of subject pool.

Subject #	*Age (years)*	*Height (cm)*	*Weight (kg)*	*Percent Body Fat*	*Resting Heart Rate (bpm)*	*GET Heart Rate (bpm)*	*Resting Systolic Pressure (mm Hg)*	*GET Systolic Pressure (mm Hg)*	*Resting Diastolic Pressure (mm Hg)*	*GET Diastolic Pressure (mm Hg)*
db	25	178	81.2	17%	68	140	106	136	68	64
me	24	180	74.4	18%	72	170	120	148	70	68
sp	26	175	73.9	11%	72	150	124	154	90	78
ed	26	173	70.8	8%	48	115	102	136	50	48
sh	22	180	77.1	14%	56	145	140	176	80	66
bs	26	191	86.2	11%	52	125	120	164	76	60
Means	**24.7**	**181.2**	**78.0**	**11%**	**52.0**	**128.3**	**120.7**	**158.7**	**68.7**	**58**

Note: "GET" indicates value at the end of the "Graded Exercise Test".

Table II

Summary of the experiments terminated early. All these experiments were in the no cooling conditions.

Subject	Experiment Duration (min.)	Final Rectal Temperature (°C)	Final Tympanic Temperature (°C)	Final Heart Rate (beats/min.)	Termination Reason
bs	110	38.6	38.2	168	3*
db	100	39.2	39.5	144	1 & 2
ed	100	38.3	39.1	155	2
me	100	38.0	38.4	172	4
sp	110	38.8	40.3	170	2

* See Early Termination of a Protocol in text for definition of codes.

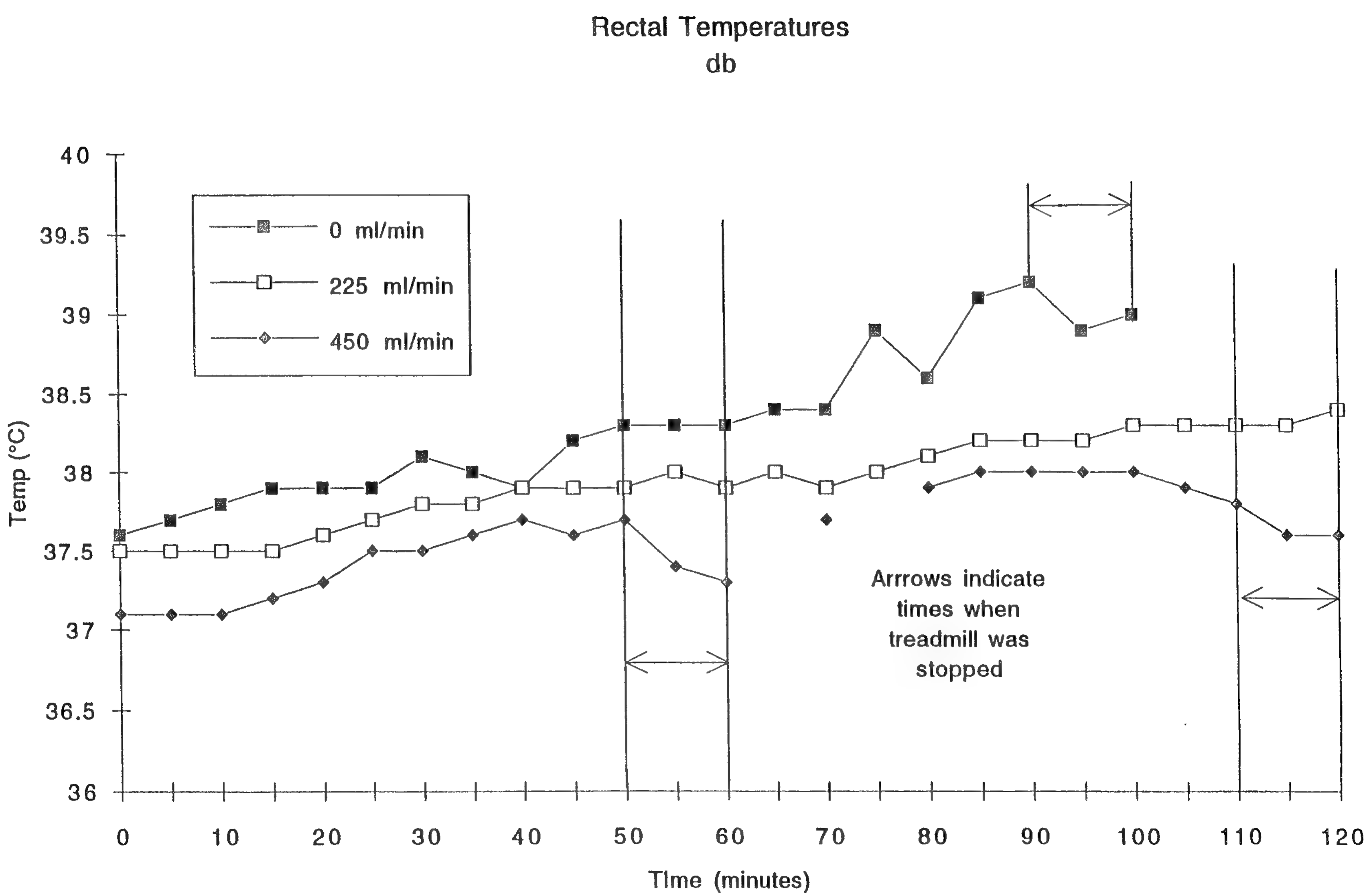

Rectal Temperatures
db
0 ml/min
225 ml/min
450 ml/min
Temp (°C)
40
39.5
39
38.5
38
37.5
37
36.5
36
0
10
20
30
40
50
60
70
80
90
100
110
120
Time (minutes)
Arrrows indicate
times when
treadmill was
stopped

FIGURE III - a.

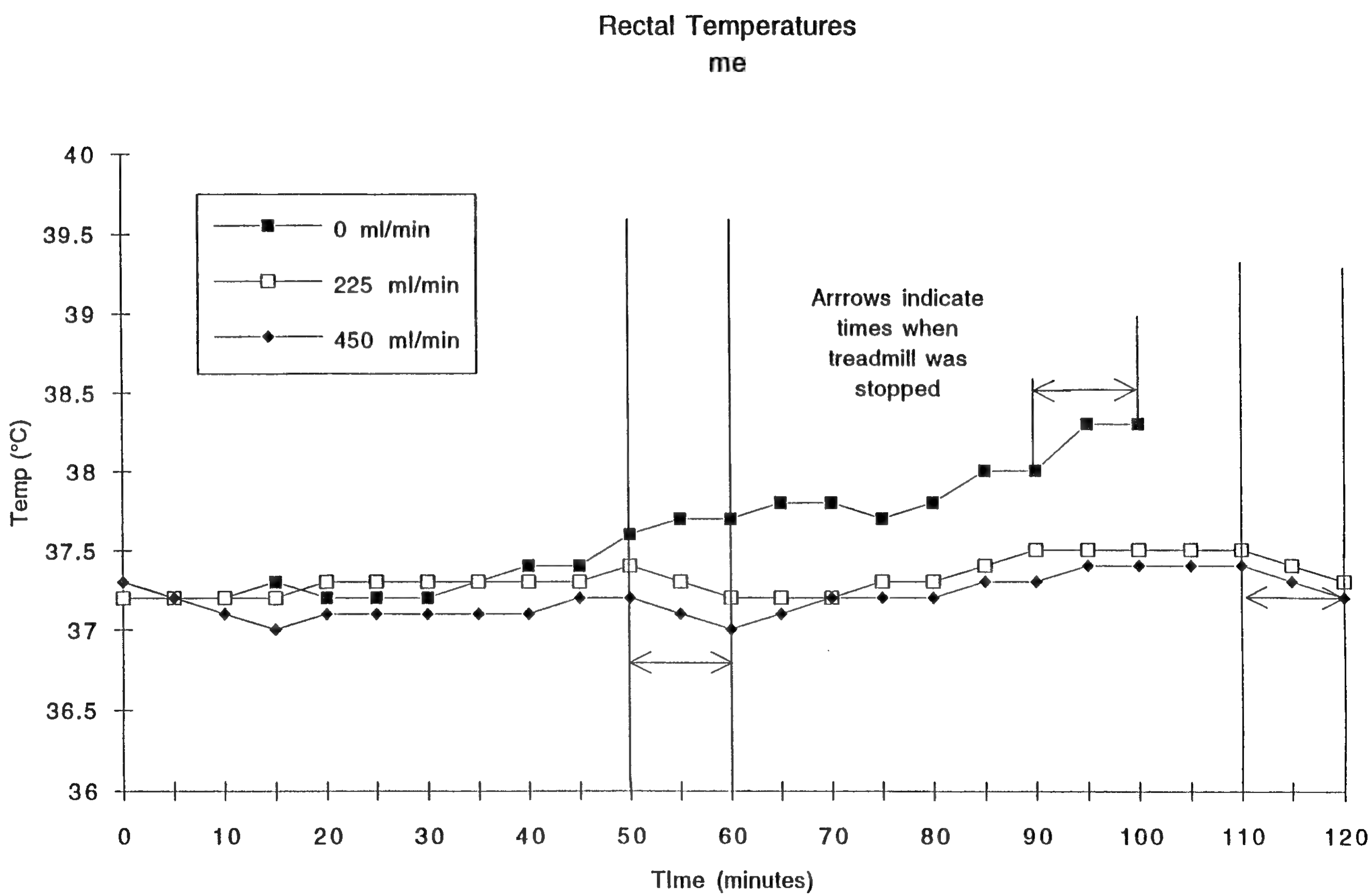

Rectal Temperatures
me
0 ml/min
225 ml/min
450 ml/min
Arrrows indicate
times when
treadmill was
stopped
Temp (°C)
40
39.5
39
38.5
38
37.5
37
36.5
36
0
10
20
30
40
50
60
70
80
90
100
110
120
TIme (minutes)

FIGURE III - b.

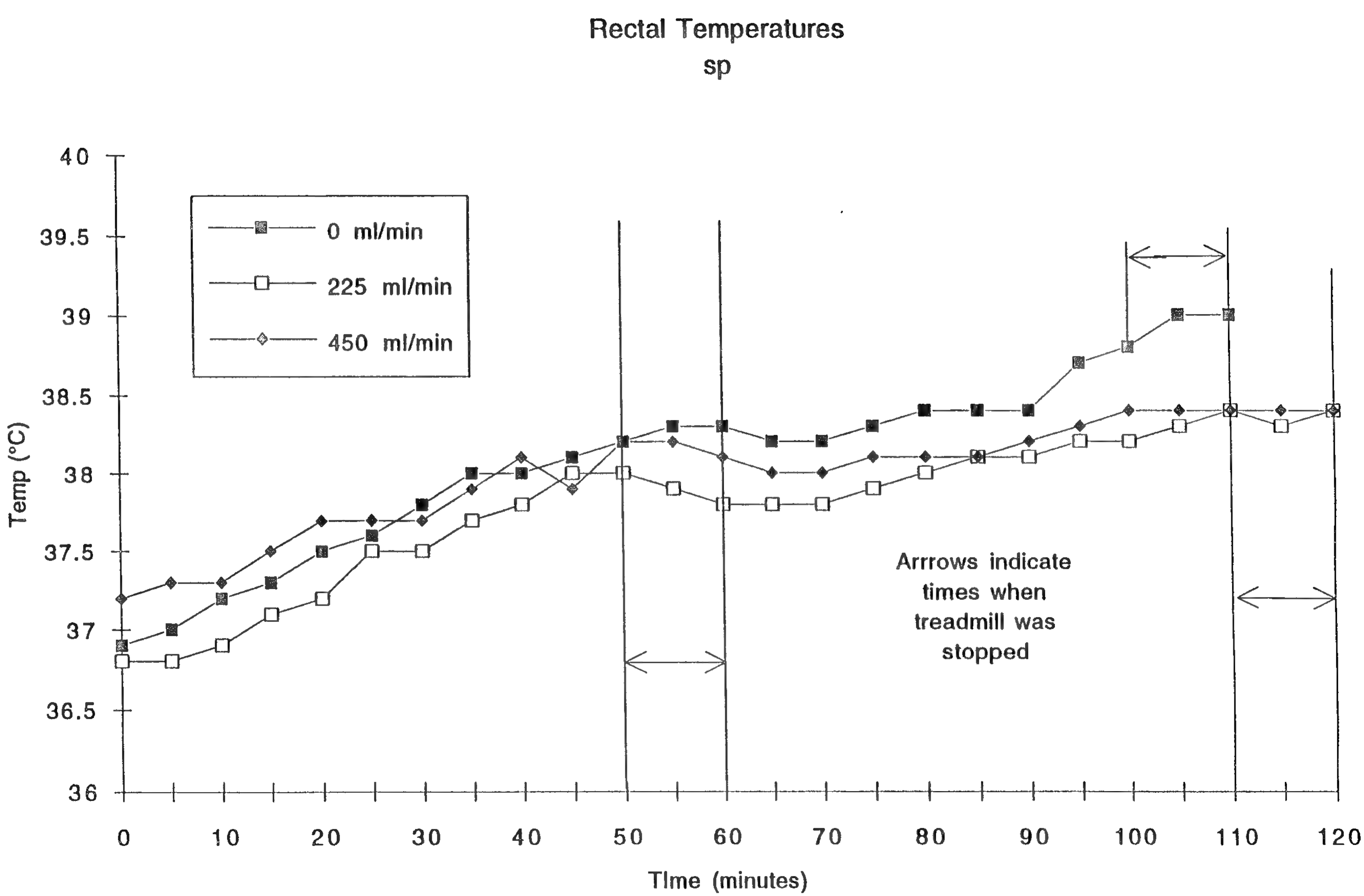

Rectal Temperatures
sp
0 ml/min
225 ml/min
450 ml/min
Arrrows indicate times when treadmill was stopped
Temp (°C)
40
39.5
39
38.5
38
37.5
37
36.5
36
0
10
20
30
40
50
60
70
80
90
100
110
120
TIme (minutes)

FIGURE III - c.

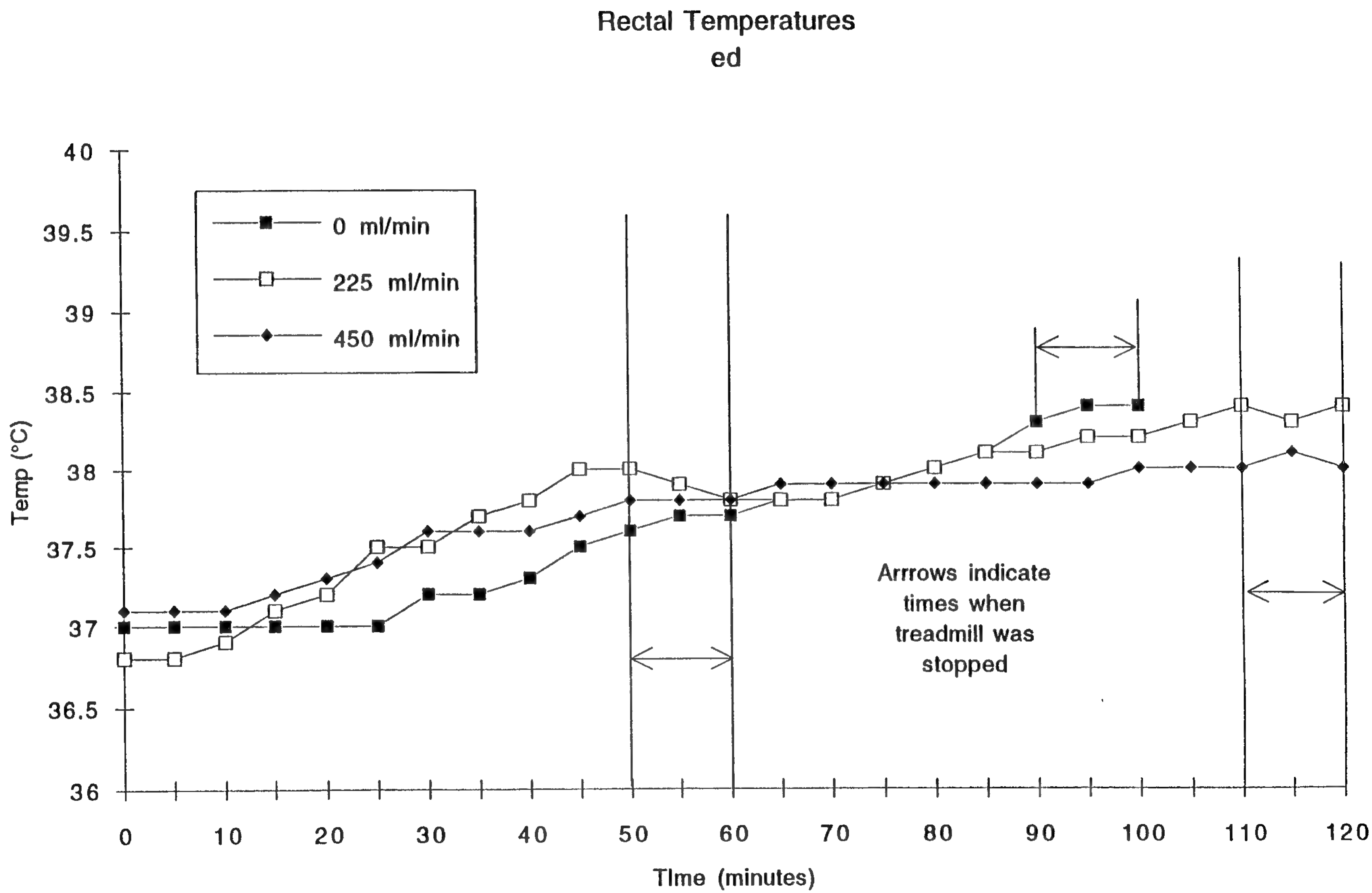

Rectal Temperatures
ed
0 ml/min
225 ml/min
450 ml/min
40
39.5
39
38.5
38
37.5
37
36.5
36
Temp (°C)
0
10
20
30
40
50
60
70
80
90
100
110
120
TIme (minutes)
Arrrows indicate
times when
treadmill was
stopped

FIGURE III - d.

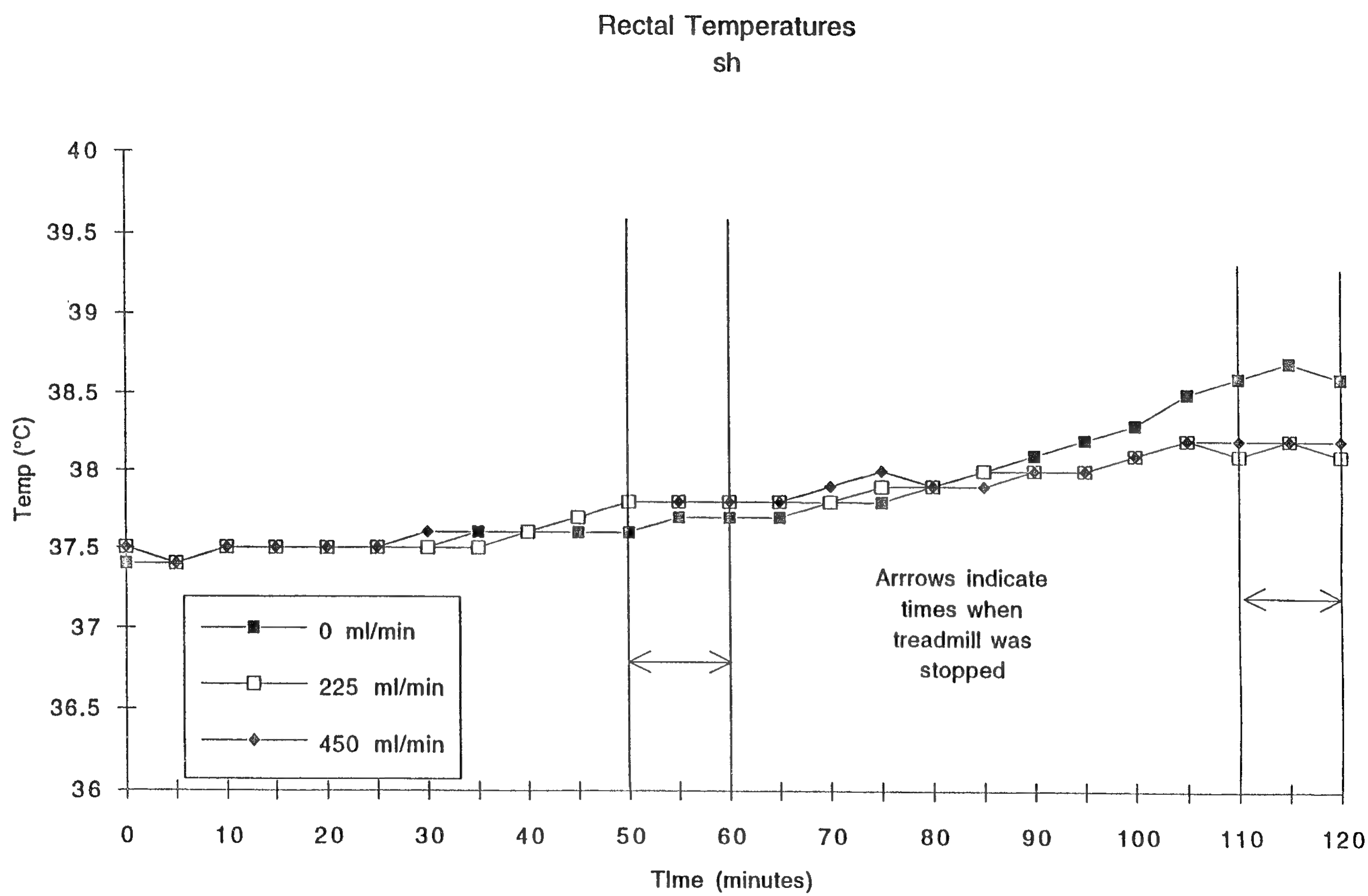
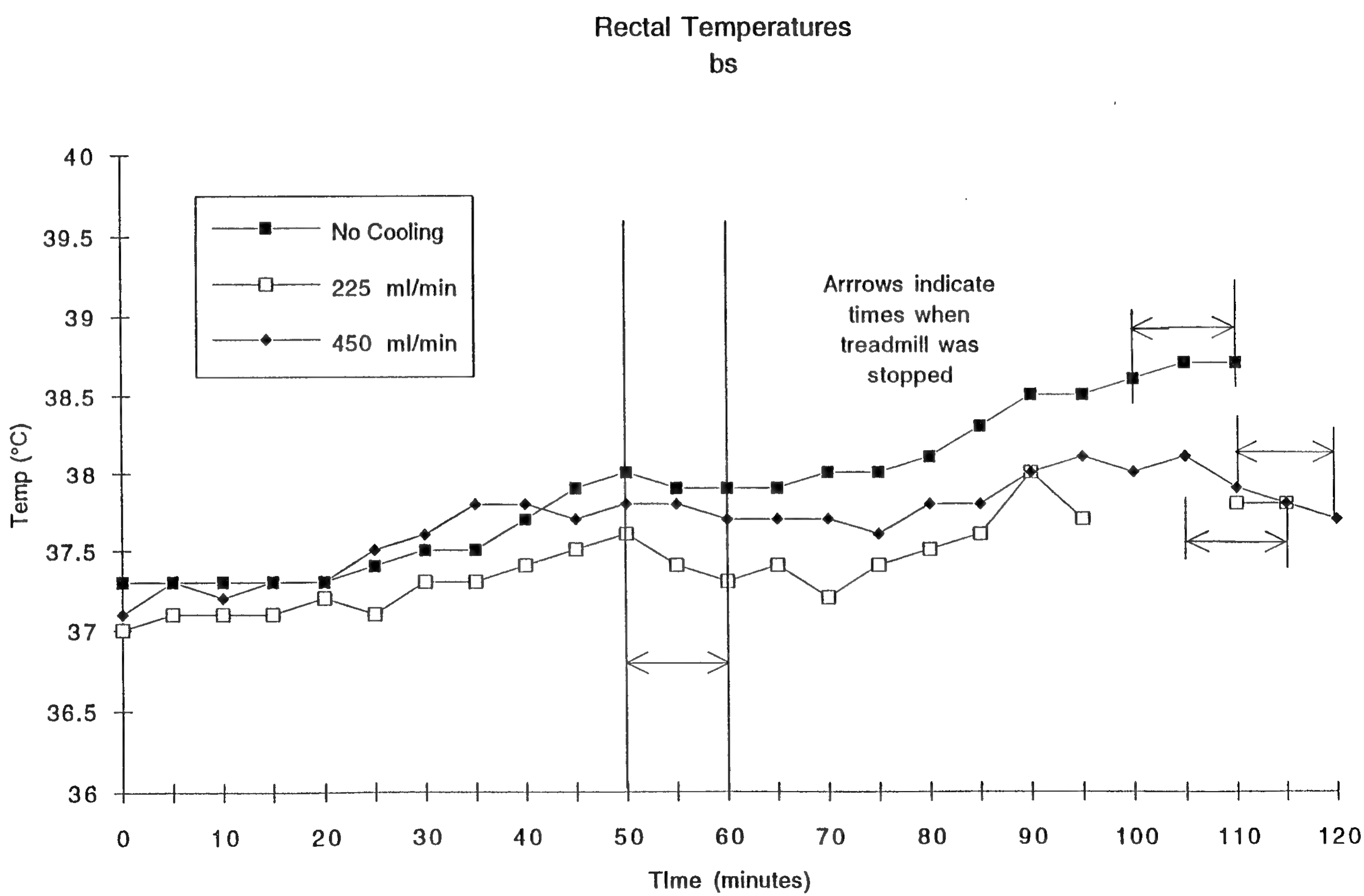

Rectal Temperatures
sh
40
39.5
39
38.5
38
37.5
37
36.5
36
Temp (°C)
0
10
20
30
40
50
60
70
80
90
100
110
120
Tlme (minutes)
0 ml/min
225 ml/min
450 ml/min
Arrrows indicate
times when
treadmill was
stopped

FIGURE III - e.



Rectal Temperatures
bs
No Cooling
225 ml/min
450 ml/min
Arrrows indicate
times when
treadmill was
stopped
Temp (°C)
40
39.5
39
38.5
38
37.5
37
36.5
36
0
10
20
30
40
50
60
70
80
90
100
110
120
TIme (minutes)

FIGURE III - f.

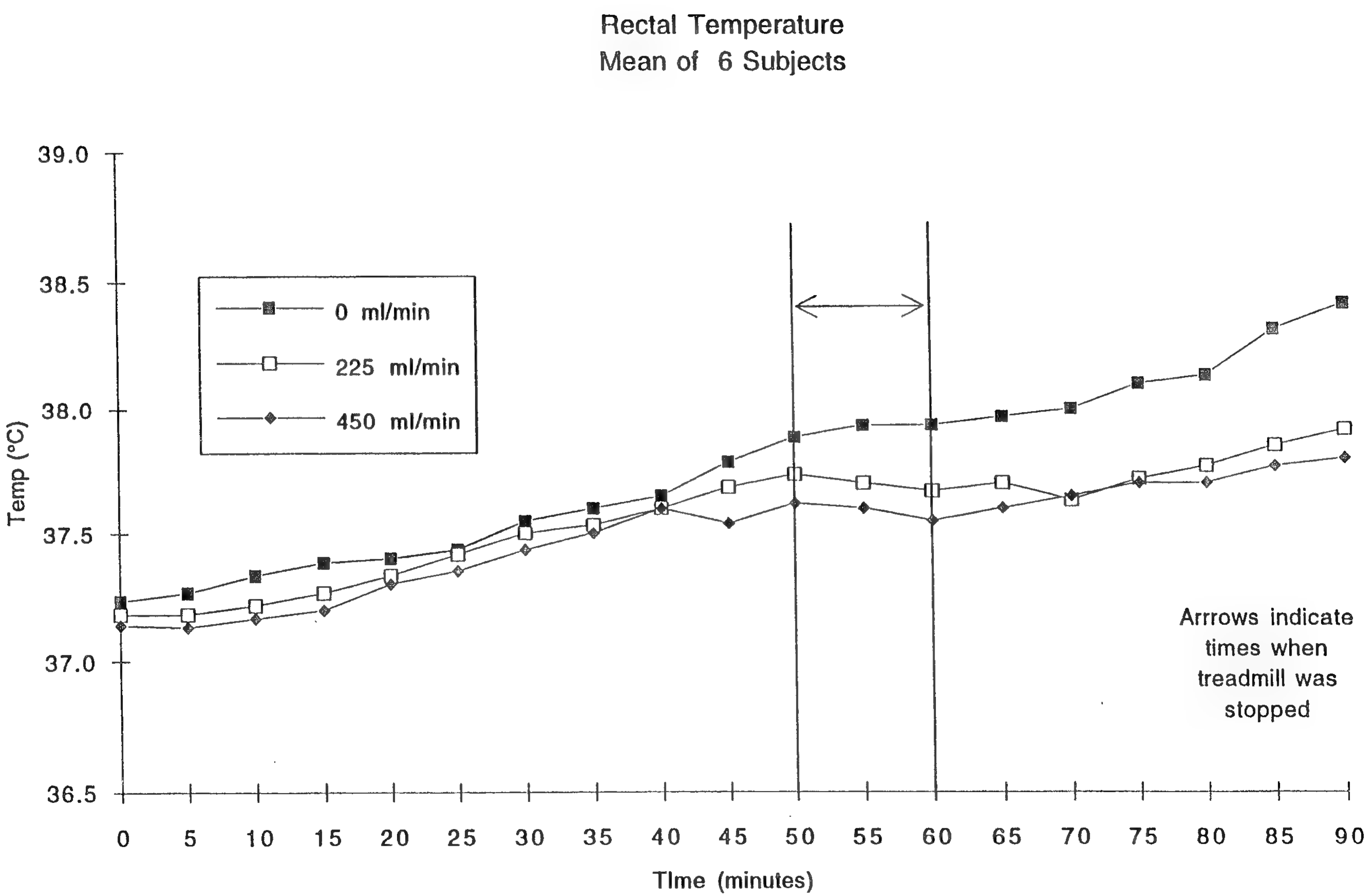

Rectal Temperature
Mean of 6 Subjects
39.0
38.5
38.0
37.5
37.0
36.5
Temp (°C)
0 ml/min
225 ml/min
450 ml/min
Arrrows indicate
times when
treadmill was
stopped
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
TIme (minutes)

FIGURE IV.

Time dependent changes in tympanic temperature for each individual subject and for the three experimental conditions are presented in Figures V (a-f). The mean of the 6 subjects for the three conditions is presented in Figure VI. In general, the tympanic temperatures were higher than the rectal temperatures both at the onset of the experiment and throughout each of the protocols. There was no significant difference in tympanic temperatures between the two cooling protocols, and tympanic temperatures in both of the cooling protocols were lower than those observed in the control experiments.

Time dependent changes in skin temperature (as monitored over the thigh) for each individual subject and for the three experimental conditions are presented in Figures VII (a-f). The mean of the 6 subjects for the three conditions is presented in Figure VIII. The skin temperature response showed a slow rise during the first 50 min of exercise with little change during the second hour of the experiment. There was no significant difference in this measure of skin temperature between either the two conditions of cooling or the control experiments.

Cardiovascular Parameters:

Time dependent changes in heart rate for each individual subject and for the three experimental conditions are presented in Figures IX (a-f). The mean of the 6 subjects for the three conditions is presented in Figure X. The heart rate showed a steady increase during both exercise phases of the experiment under all conditions. However, the heart rate was higher with no cooling and was not significantly different when the two cooling conditions were compared (see Figure X). In 2 subjects in the no cool situation, the experiment was terminated early due to excessively high heart rates as defined under items 3 or 4 of the "early termination" criteria of the protocol (see Figures I, b & c).

Time dependent changes in systolic blood pressures for each individual subject and for the three experimental conditions are presented in Figures XI (a-f). The mean of the 6 subjects for the three conditions is presented in Figure XII. There is considerable variability in this parameter, but in general there is an early rise in systolic blood pressure with a subsequent stabilization during the second exercise period.

Time dependent changes in diastolic blood pressure for each individual subject and for the three experimental conditions are presented in Figures XIII (a-f). The mean of the 6 subjects for the three conditions is presented in Figure XIV. Again there is no consistent pattern in diastolic pressure changes, and the mean values indicate that there are no significant differences between conditions.

The mean blood pressure (MBP) was calculated as follows: MBP - DBP + 1/3 PP, where DBP is the diastolic blood pressure and PP is the pulse pressure (systolic-diastolic blood pressure). Time dependent changes in mean blood pressure for each individual subject and for the three experimental conditions are presented in Figures XV (a-f). The mean of the 6 subjects for the three conditions is presented in Figure XVI. There is no consistent pattern in mean blood pressure changes and there are no significant differences between conditions or over time.

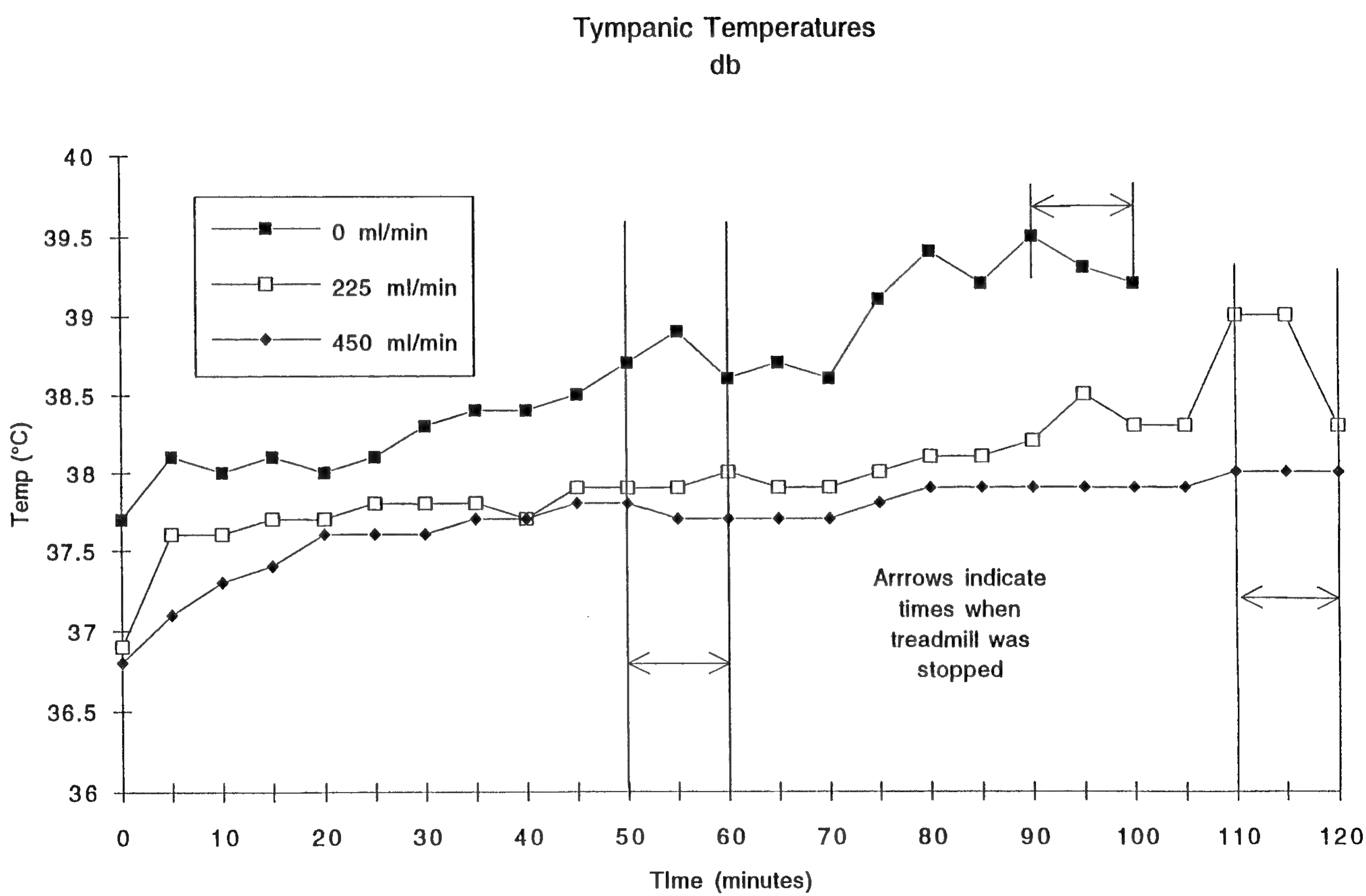

Tympanic Temperatures
db
0 ml/min
225 ml/min
450 ml/min
Temp (°C)
40
39.5
39
38.5
38
37.5
37
36.5
36
0
10
20
30
40
50
60
70
80
90
100
110
120
Time (minutes)
Arrrows indicate
times when
treadmill was
stopped

FIGURE V - a.

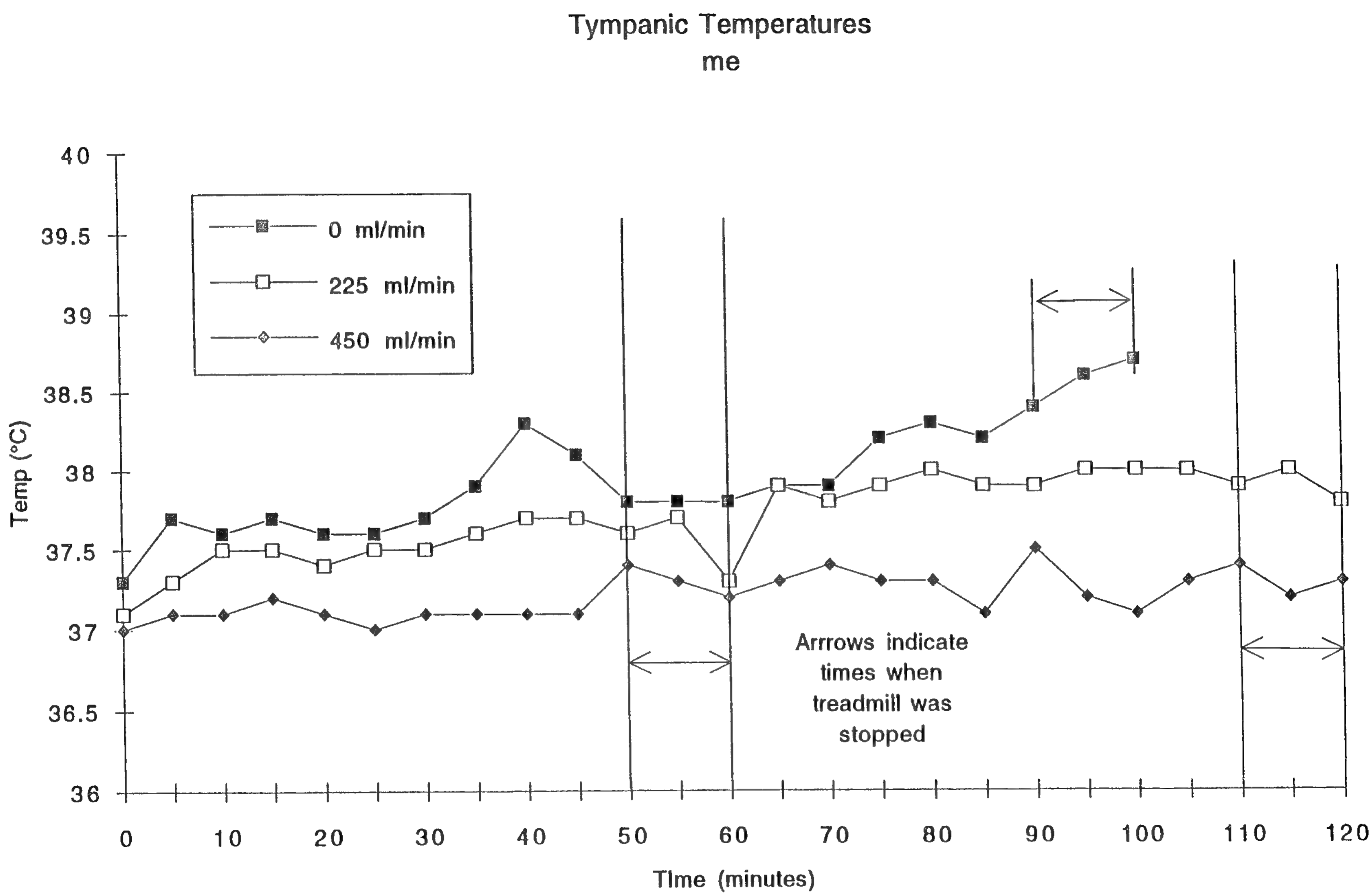

Tympanic Temperatures
me
0 ml/min
225 ml/min
450 ml/min
Temp (°C)
40
39.5
39
38.5
38
37.5
37
36.5
36
0
10
20
30
40
50
60
70
80
90
100
110
120
Time (minutes)
Arrrows indicate
times when
treadmill was
stopped

FIGURE V - b.

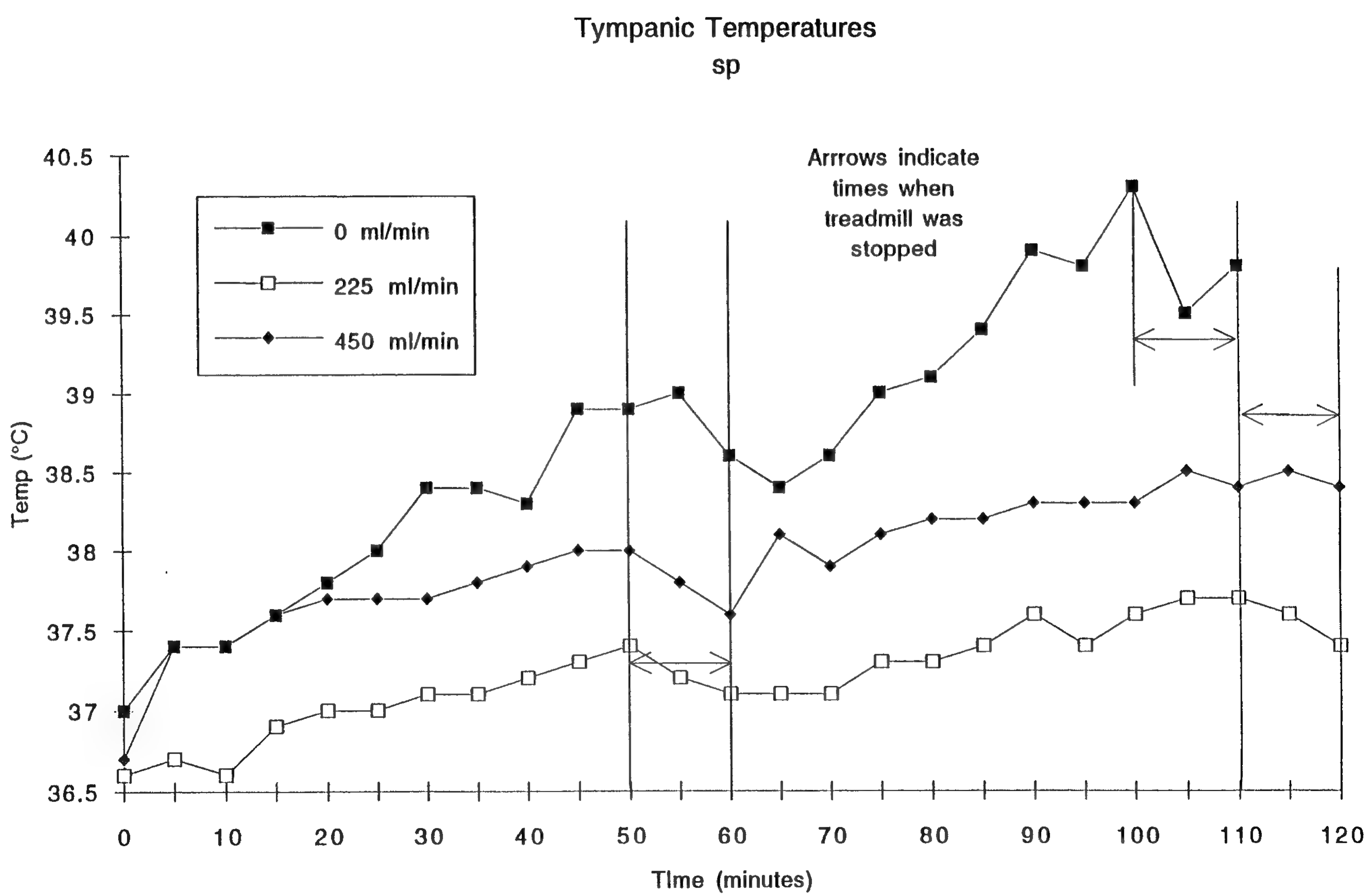

Tympanic Temperatures
sp
Arrrows indicate times when treadmill was stopped
0 ml/min
225 ml/min
450 ml/min
Temp (°C)
40.5
40
39.5
39
38.5
38
37.5
37
36.5
0
10
20
30
40
50
60
70
80
90
100
110
120
TIme (minutes)

FIGURE V - c.

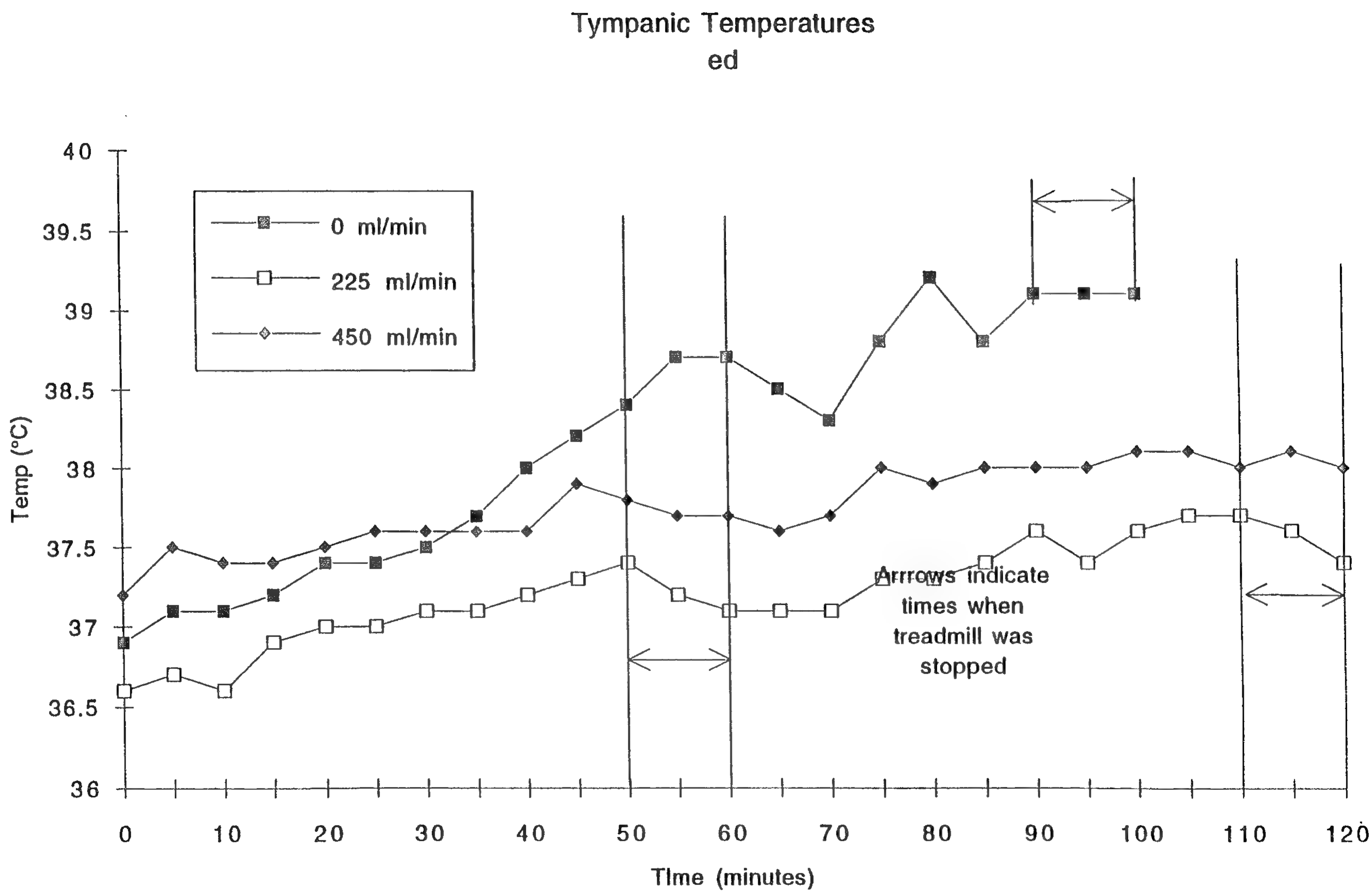

Tympanic Temperatures
ed
0 ml/min
225 ml/min
450 ml/min
Temp (°C)
40
39.5
39
38.5
38
37.5
37
36.5
36
0
10
20
30
40
50
60
70
80
90
100
110
120
Time (minutes)
Arrrows indicate times when treadmill was stopped

FIGURE V - d.

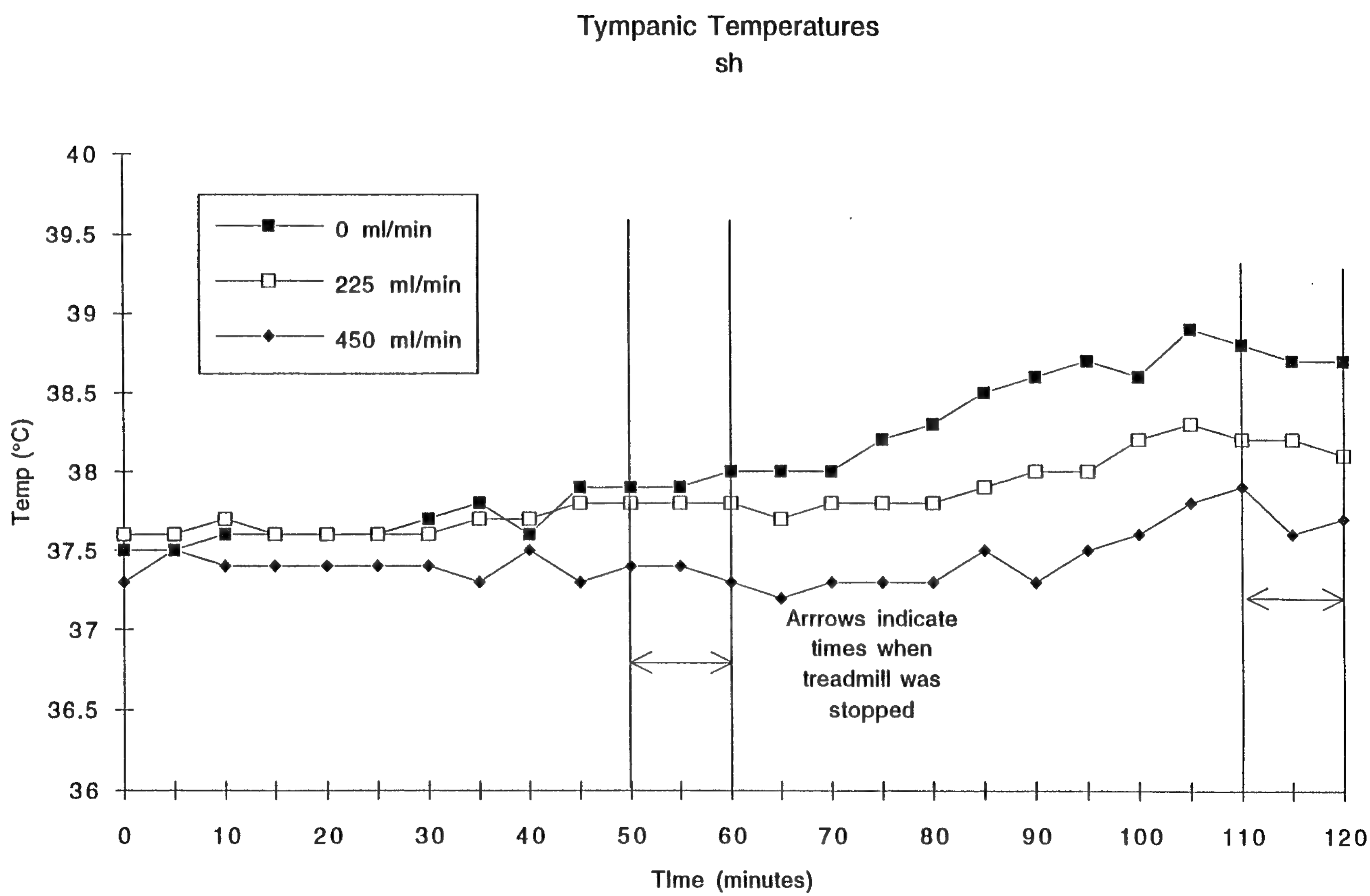

Tympanic Temperatures
sh
0 ml/min
225 ml/min
450 ml/min
Arrrows indicate times when treadmill was stopped
Temp (°C)
40
39.5
39
38.5
38
37.5
37
36.5
36
0
10
20
30
40
50
60
70
80
90
100
110
120
TIme (minutes)

FIGURE V - e.

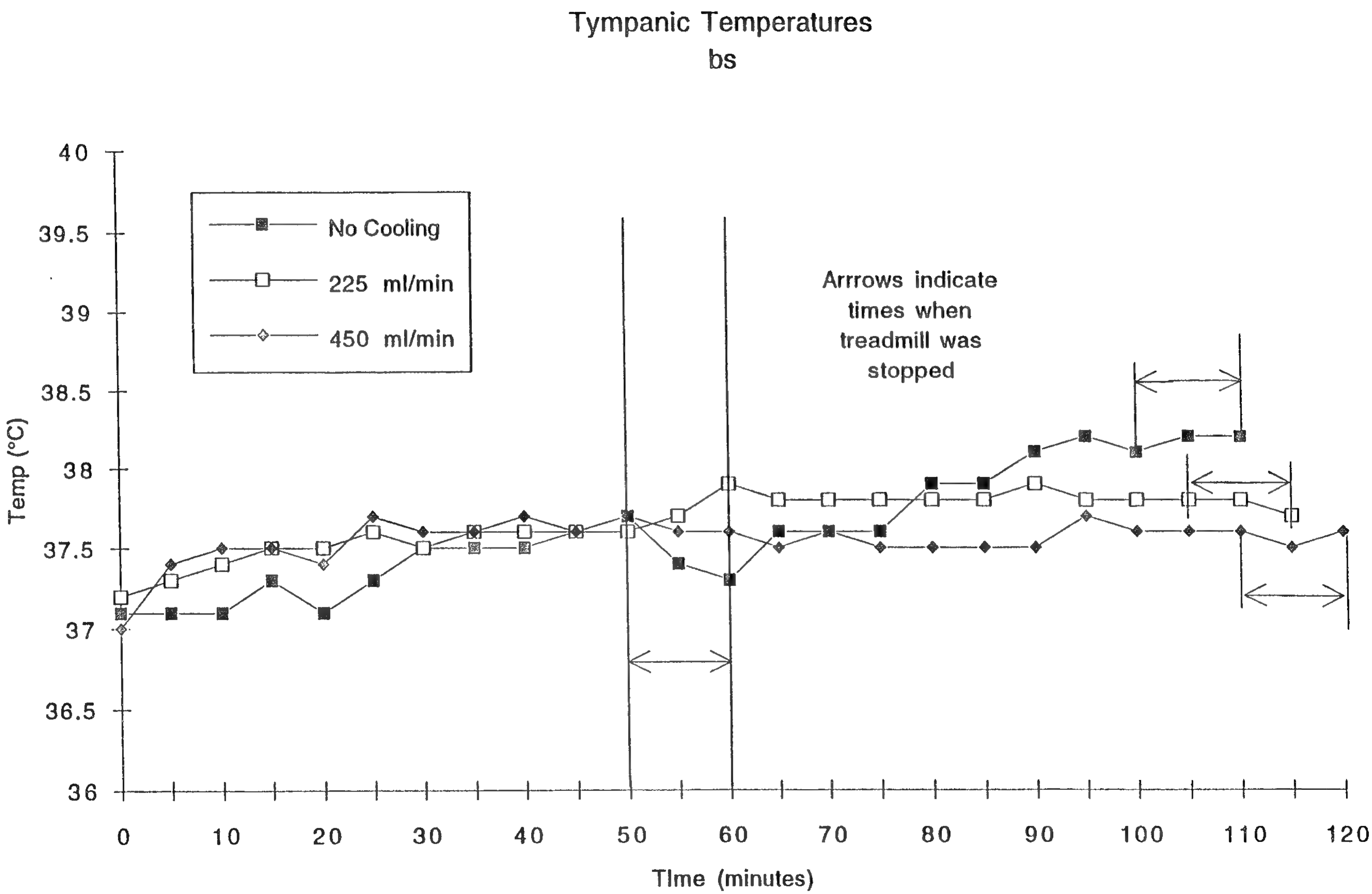

Tympanic Temperatures
bs
No Cooling
225 ml/min
450 ml/min
Arrrows indicate
times when
treadmill was
stopped
Temp (°C)
40
39.5
39
38.5
38
37.5
37
36.5
36
0
10
20
30
40
50
60
70
80
90
100
110
120
Tlme (minutes)

FIGURE V - f.

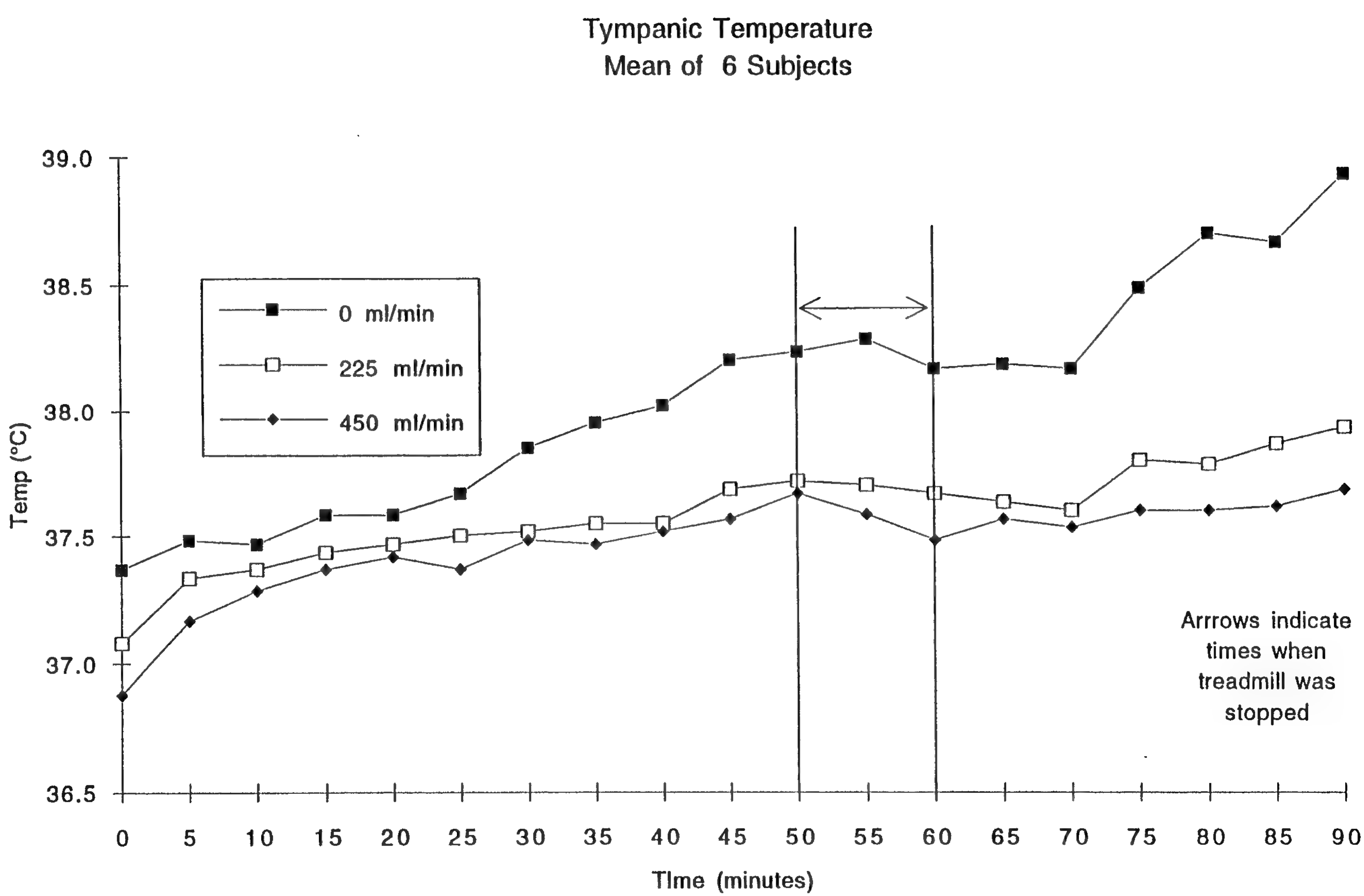

Tympanic Temperature
Mean of 6 Subjects
39.0
38.5
38.0
37.5
37.0
36.5
Temp (°C)
0 ml/min
225 ml/min
450 ml/min
Arrrows indicate
times when
treadmill was
stopped
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
TIme (minutes)

FIGURE VI.

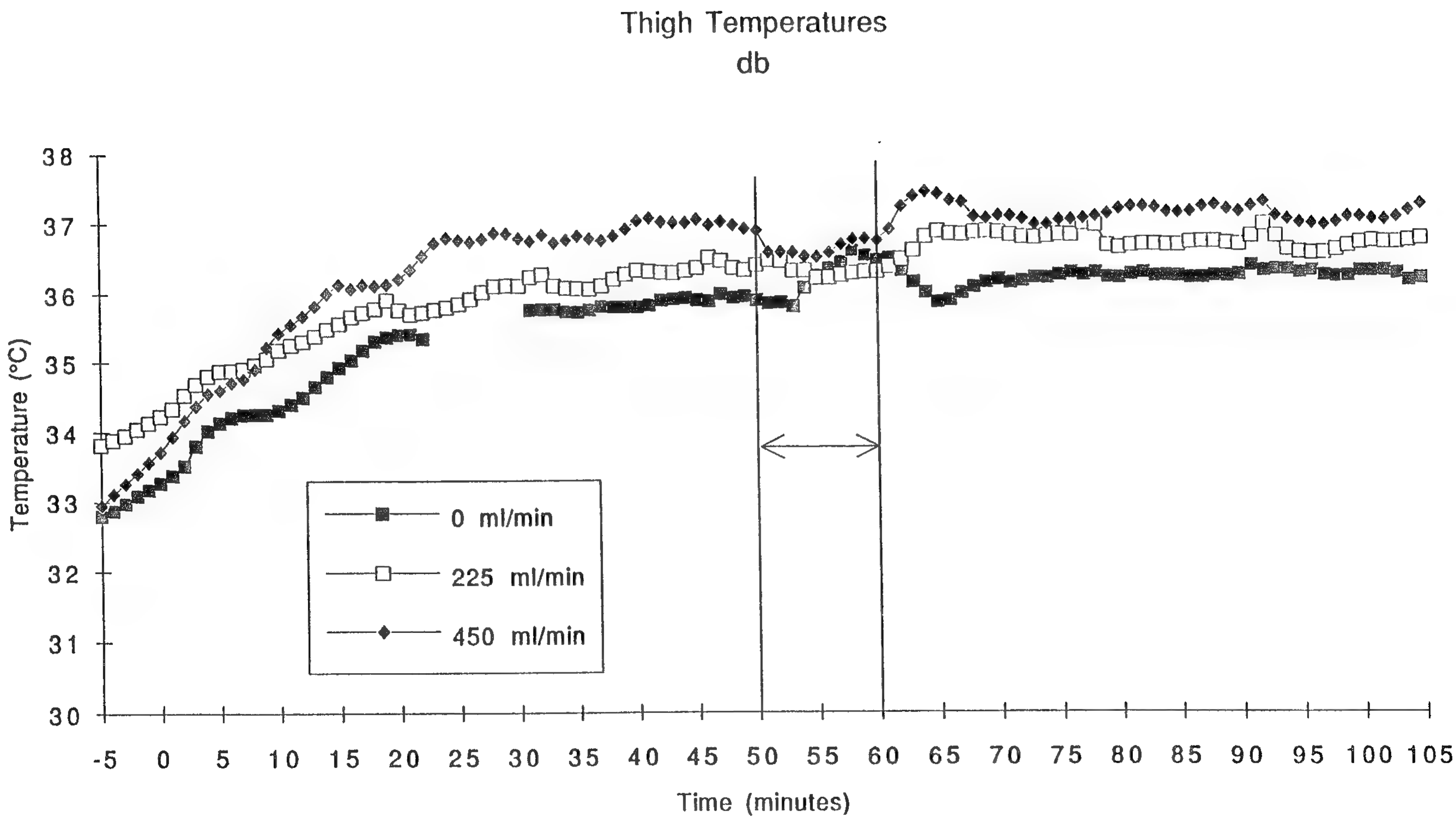

Thigh Temperatures
db
38
37
36
35
34
33
32
31
30
Temperature (°C)
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
Time (minutes)
0 ml/min
225 ml/min
450 ml/min

FIGURE VII - a.

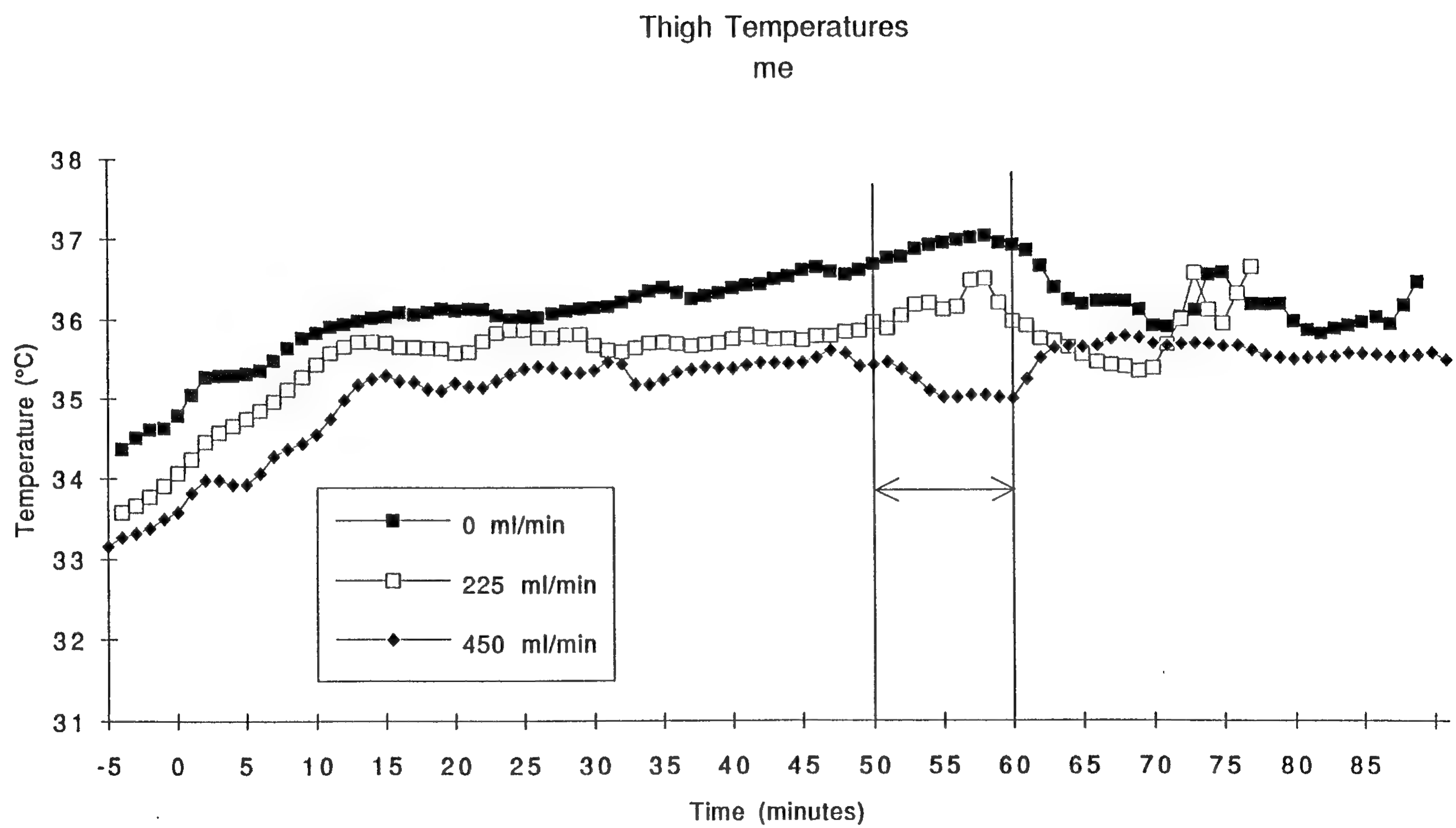

Thigh Temperatures
me
Temperature (°C)
38
37
36
35
34
33
32
31
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
Time (minutes)
0 ml/min
225 ml/min
450 ml/min

FIGURE VII - b.

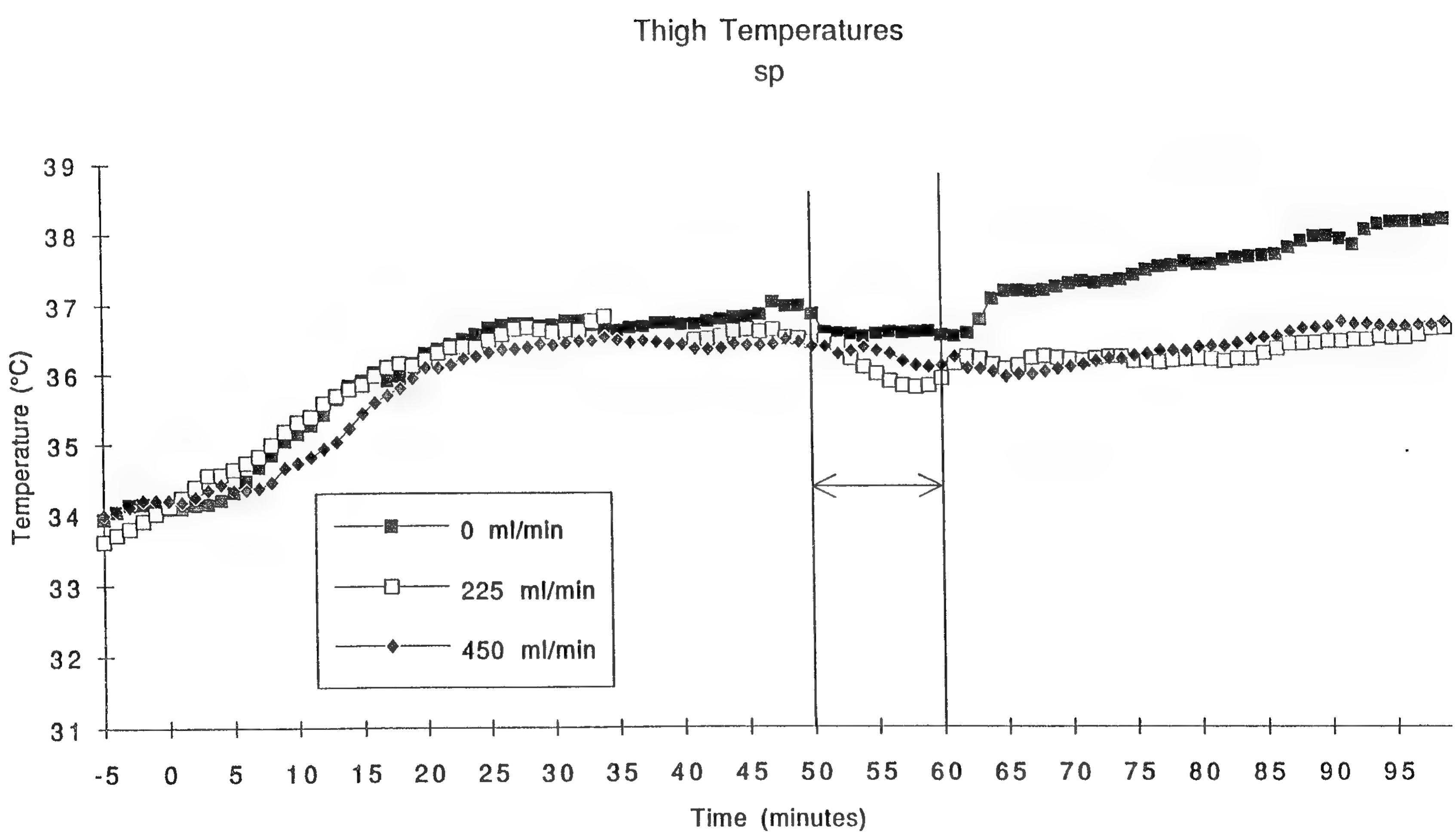
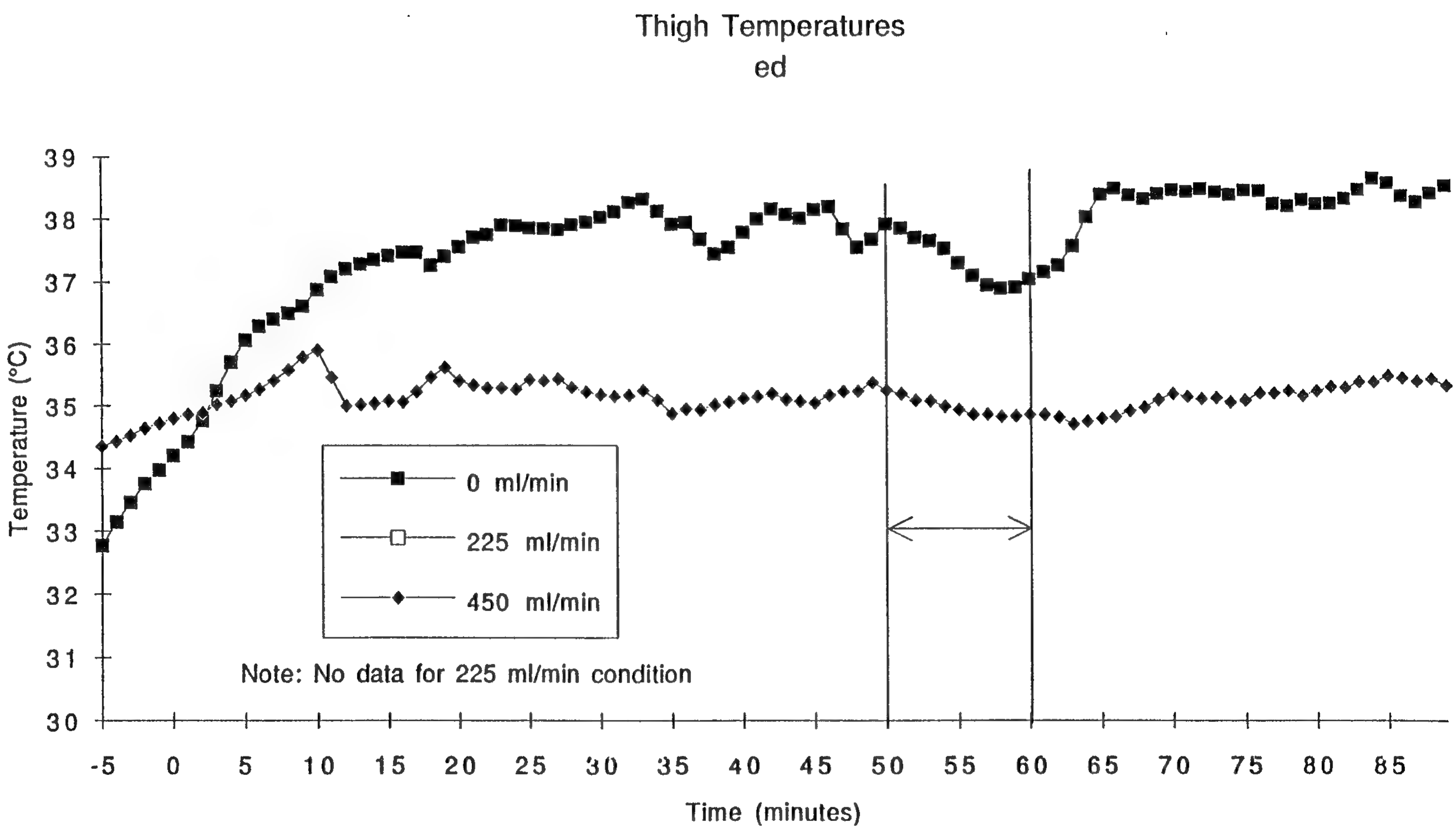

Thigh Temperatures
sp
Temperature (°C)
39
38
37
36
35
34
33
32
31
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
Time (minutes)
0 ml/min
225 ml/min
450 ml/min

FIGURE VII - c.



Note: Data lost due to equipment malfunction.

FIGURE VII - d.

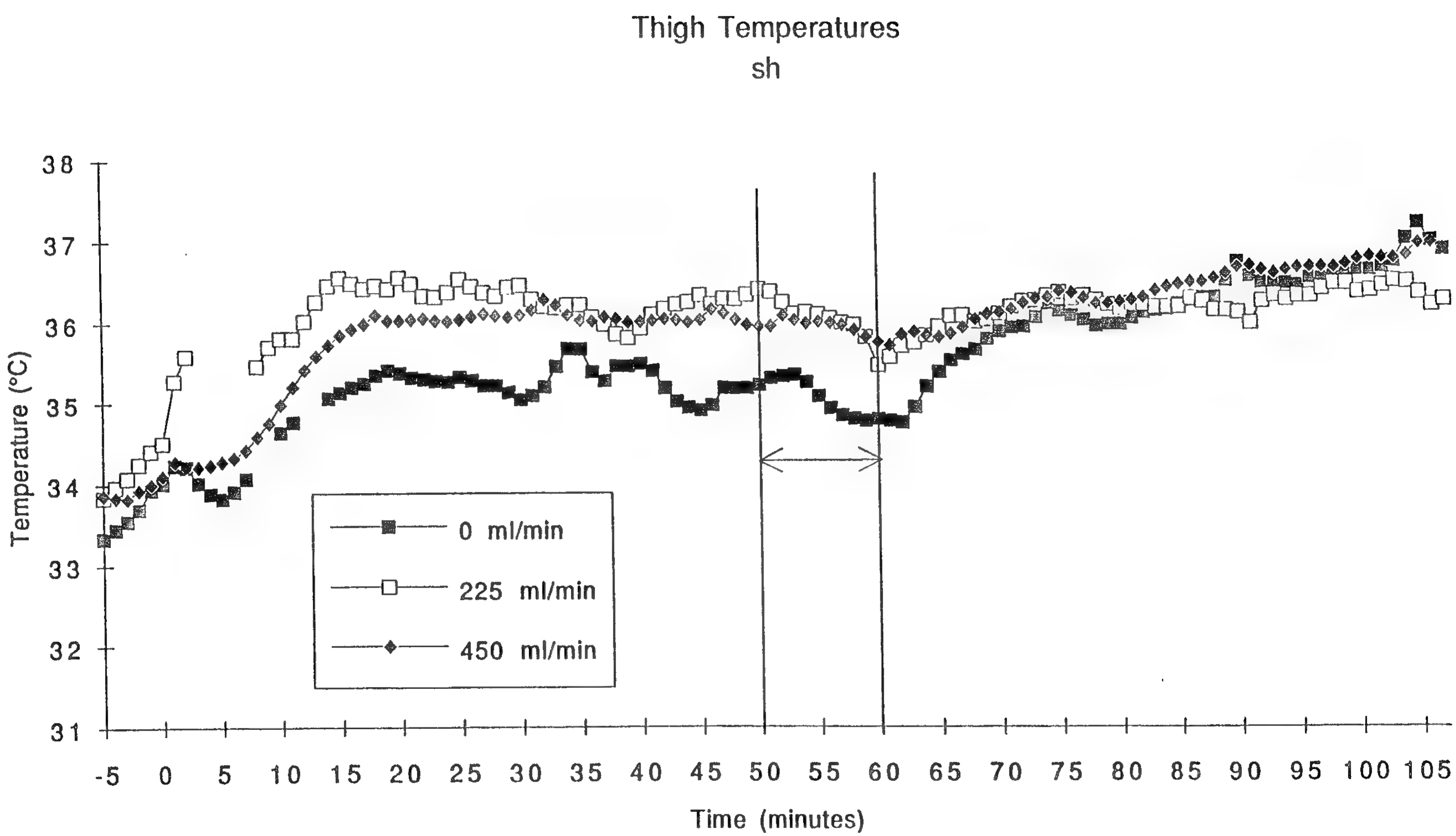
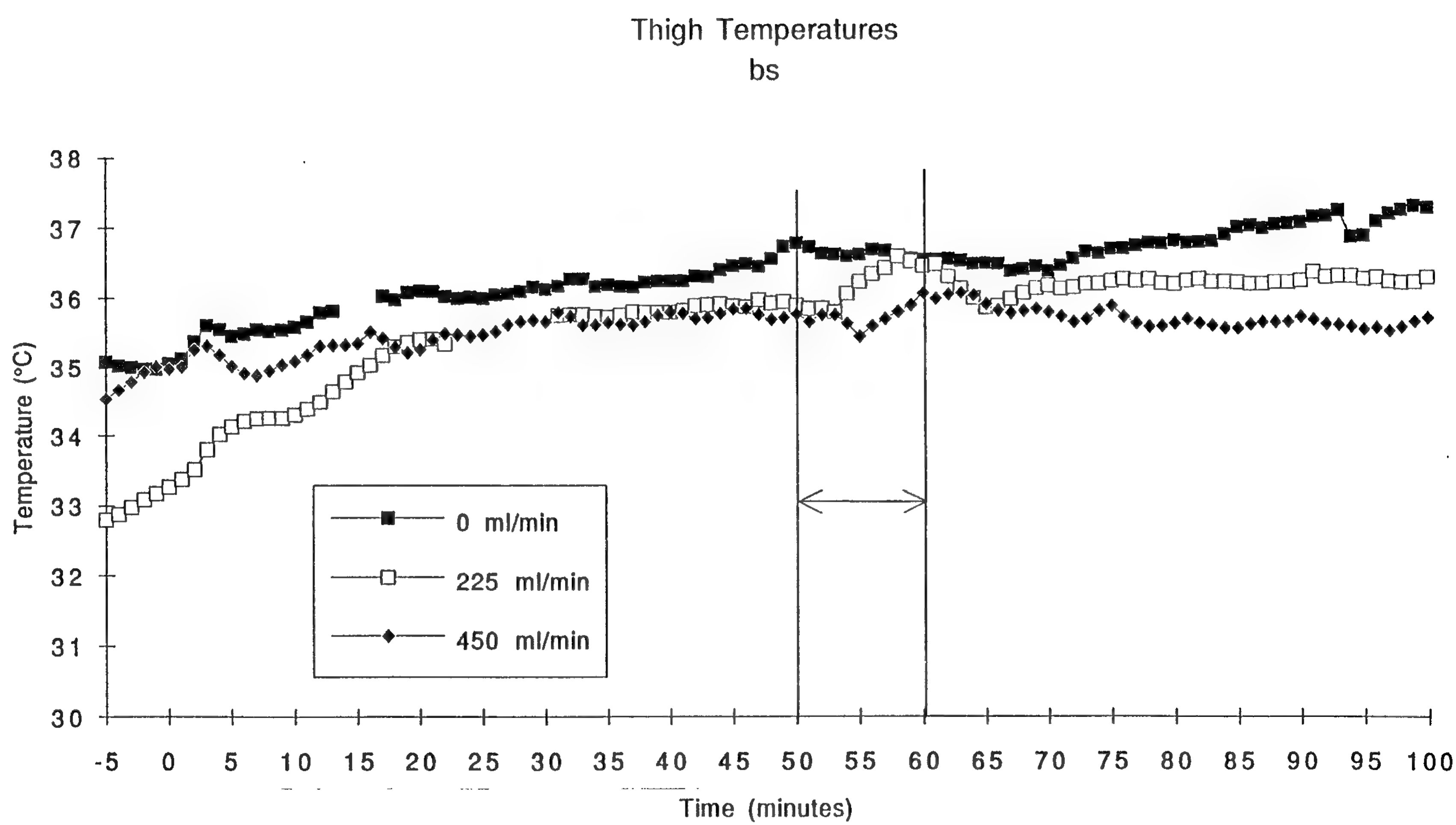

Thigh Temperatures
sh
Temperature (°C)
38
37
36
35
34
33
32
31
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
Time (minutes)
0 ml/min
225 ml/min
450 ml/min

FIGURE VII - e.



Thigh Temperatures
bs
38
37
36
35
34
33
32
31
30
Temperature (°C)
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
Time (minutes)
0 ml/min
225 ml/min
450 ml/min

FIGURE VII - f.

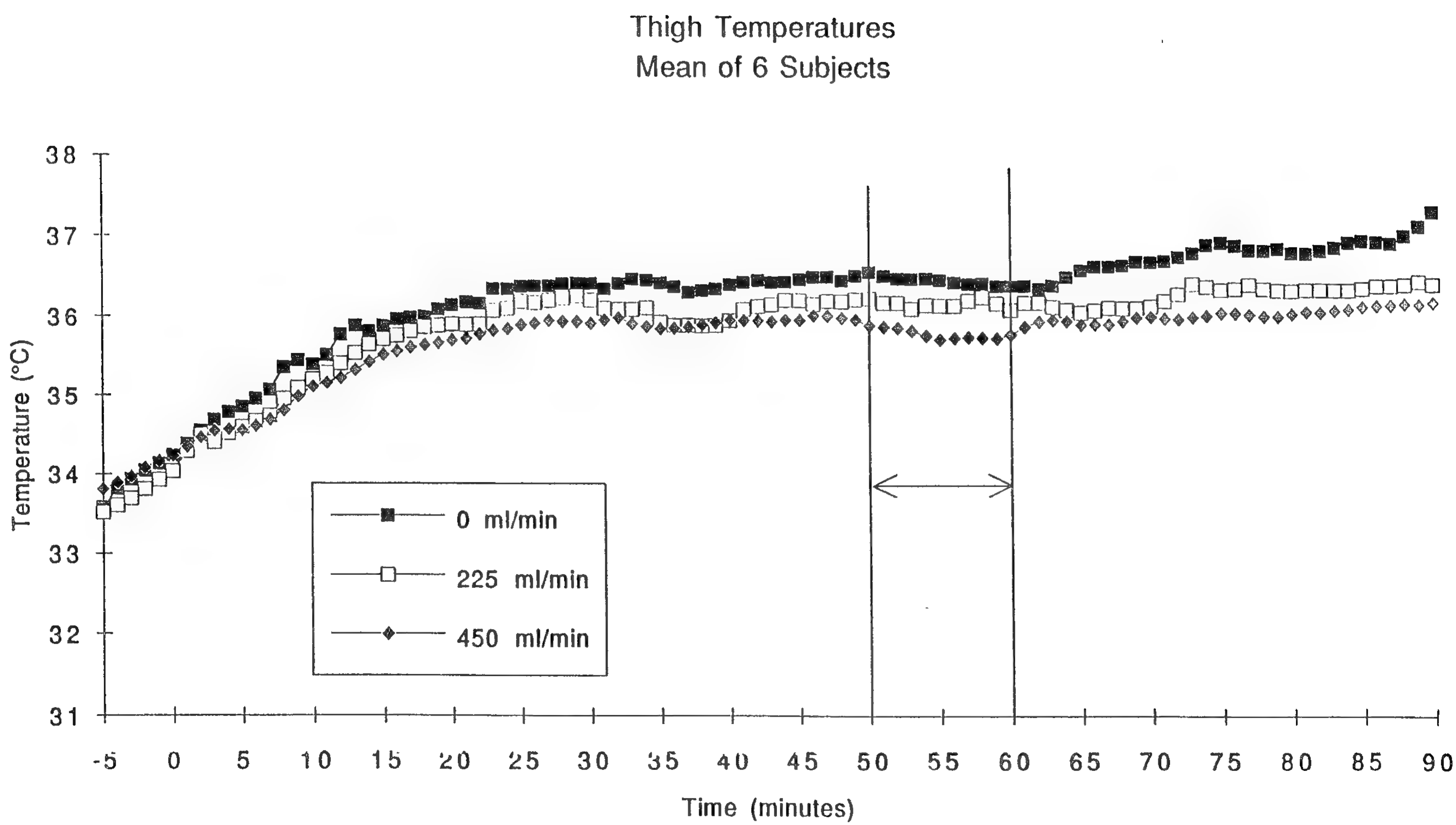

Thigh Temperatures
Mean of 6 Subjects
Temperature (°C)
38
37
36
35
34
33
32
31
0 ml/min
225 ml/min
450 ml/min
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
Time (minutes)

FIGURE VIII.

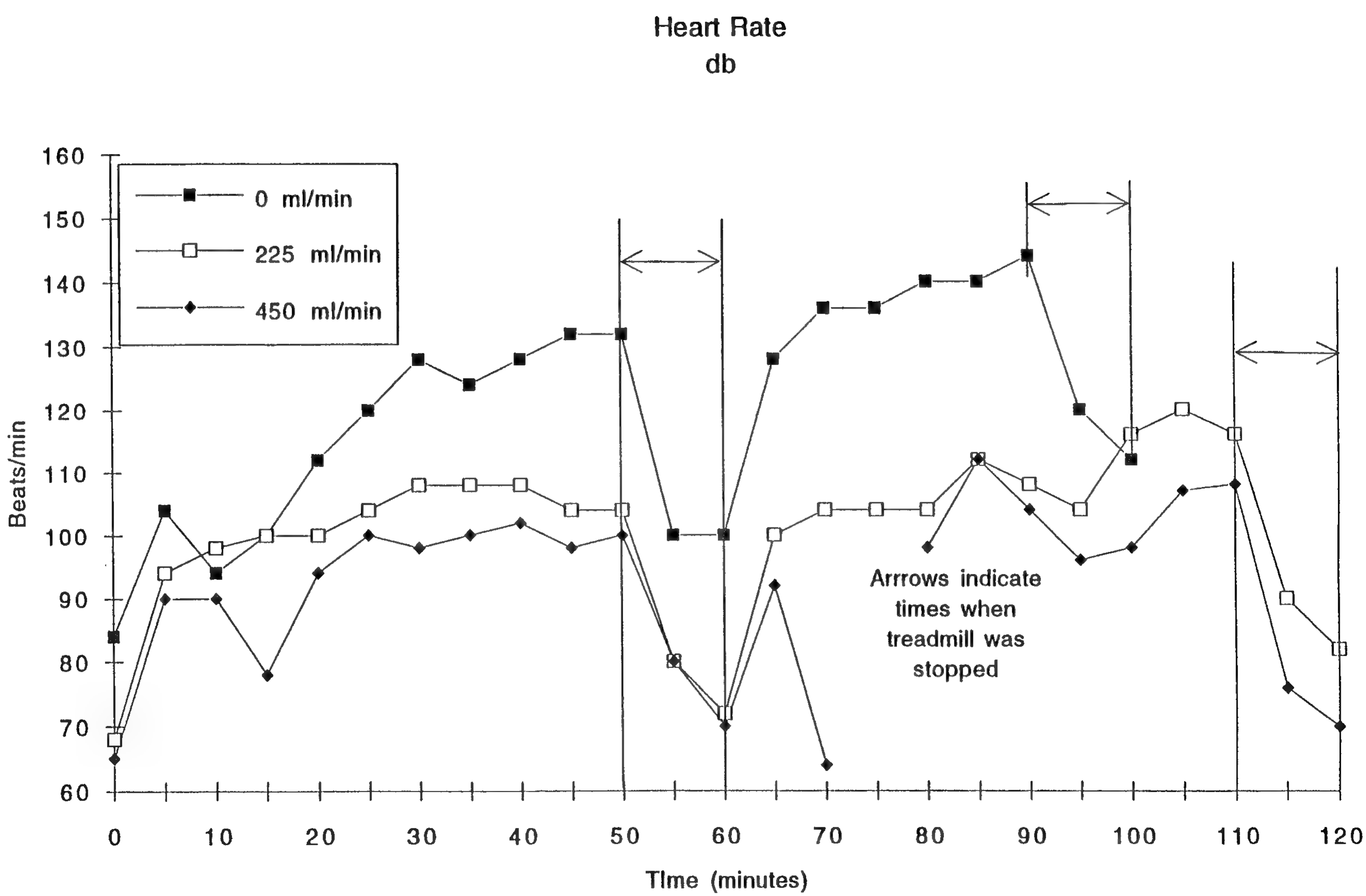

Heart Rate
db
0 ml/min
225 ml/min
450 ml/min
Beats/min
160
150
140
130
120
110
100
90
80
70
60
0
10
20
30
40
50
60
70
80
90
100
110
120
TIme (minutes)
Arrrows indicate
times when
treadmill was
stopped

FIGURE IX - a.

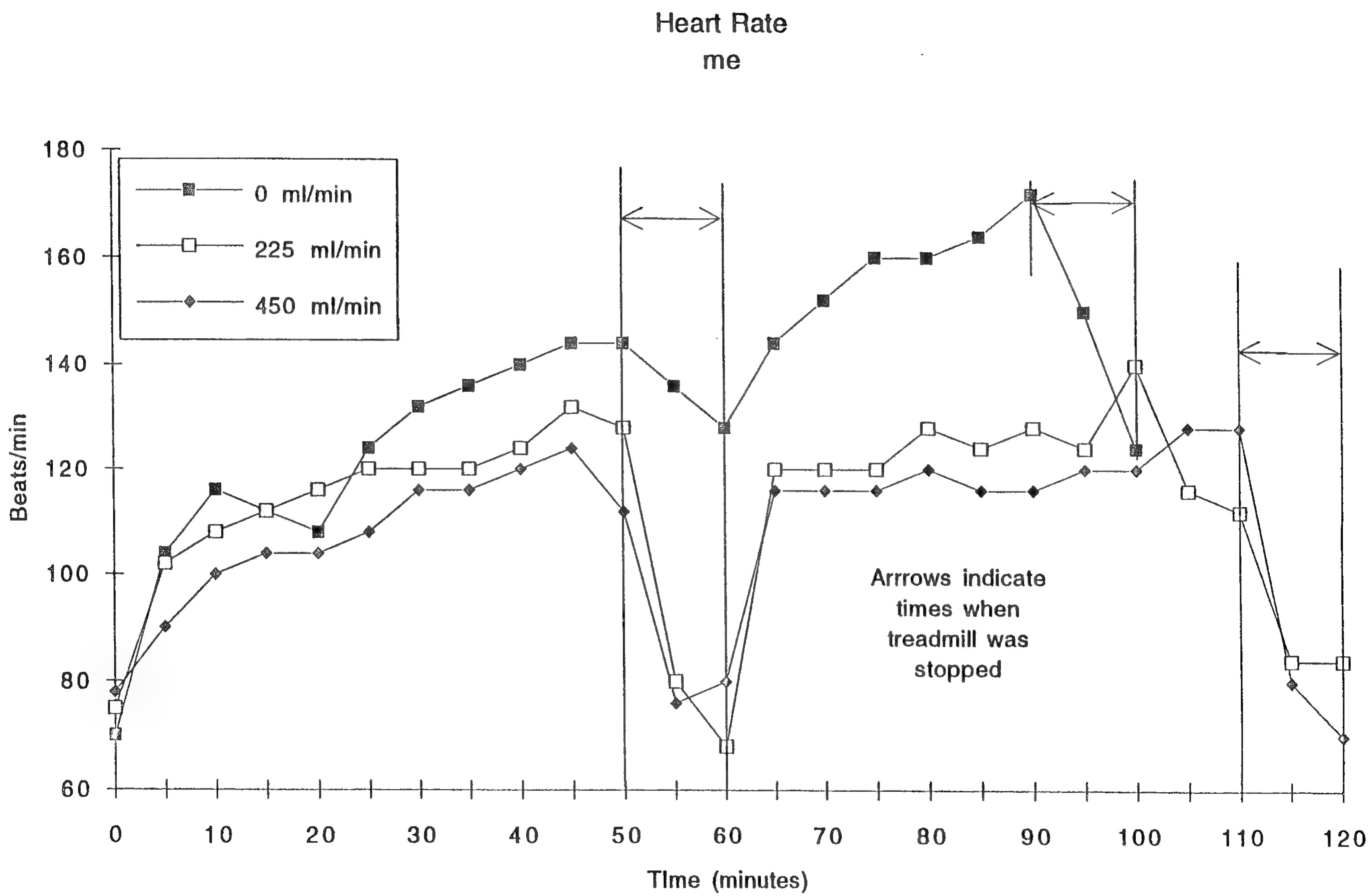
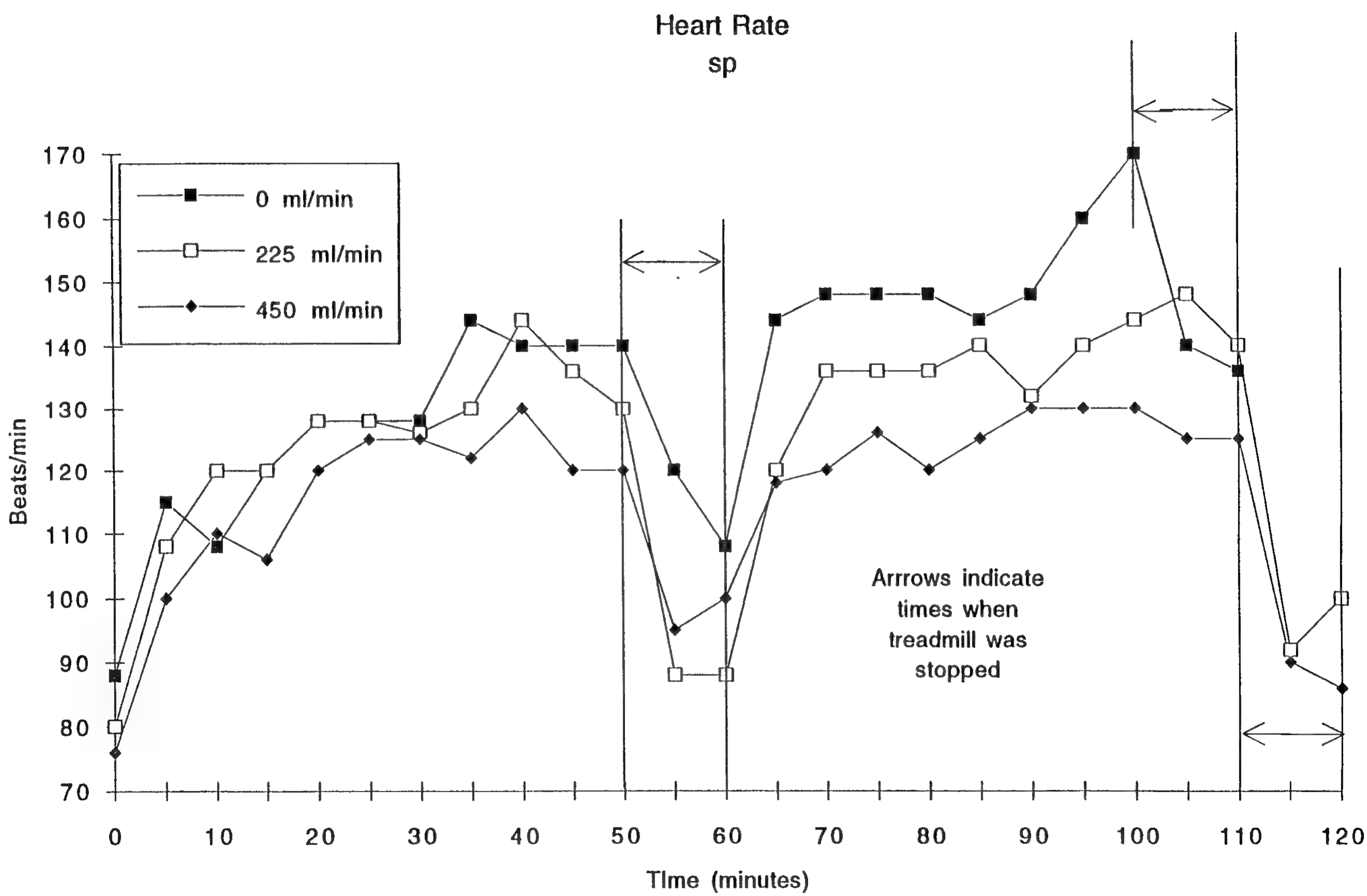

Heart Rate
me
0 ml/min
225 ml/min
450 ml/min
Beats/min
180
160
140
120
100
80
60
0
10
20
30
40
50
60
70
80
90
100
110
120
Time (minutes)
Arrrows indicate
times when
treadmill was
stopped

FIGURE IX - b.



Heart Rate
sp
0 ml/min
225 ml/min
450 ml/min
Beats/min
170
160
150
140
130
120
110
100
90
80
70
0
10
20
30
40
50
60
70
80
90
100
110
120
Tlme (minutes)
Arrrows indicate times when treadmill was stopped

FIGURE IX - c.

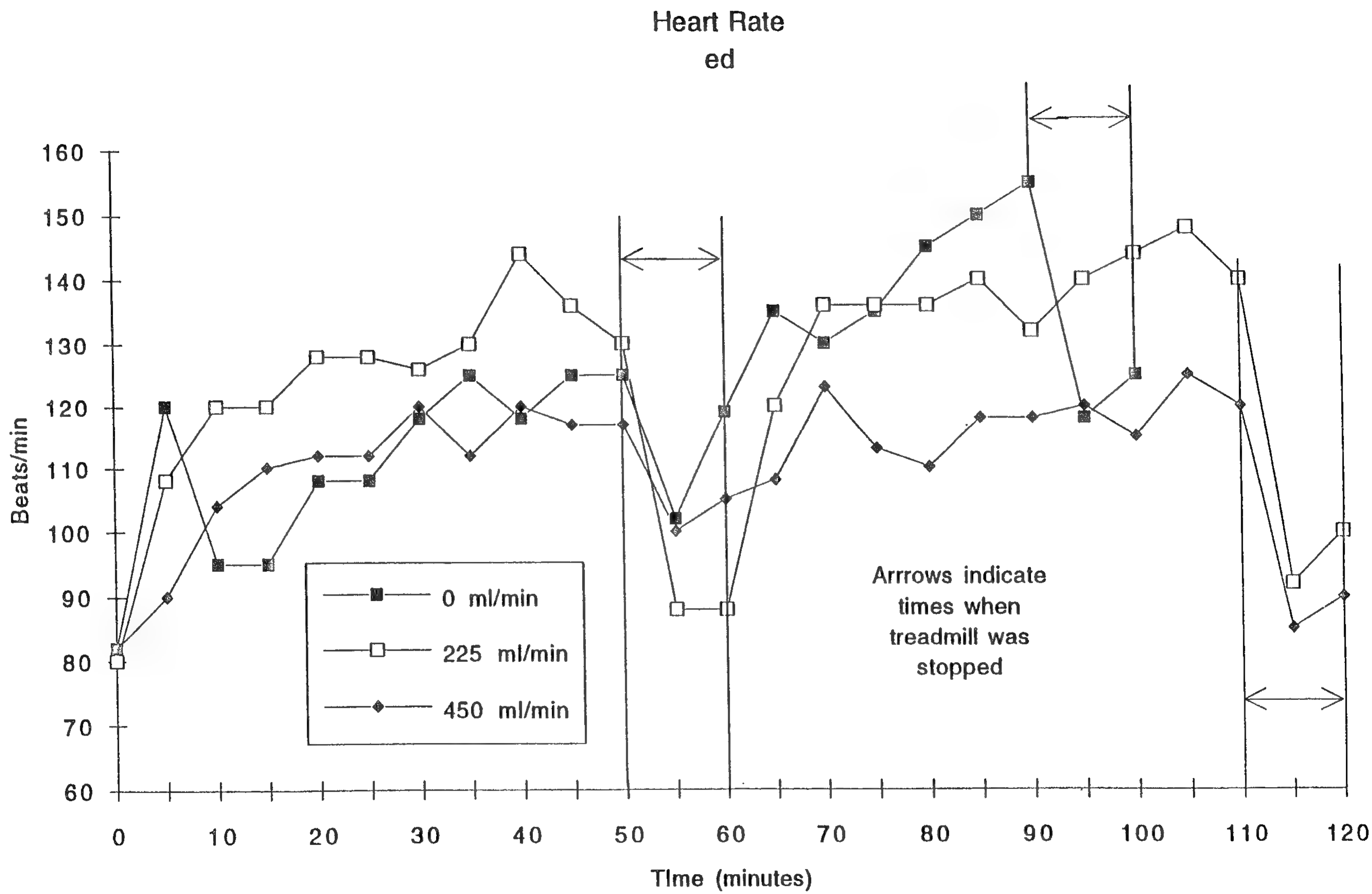

Heart Rate
ed
Beats/min
160
150
140
130
120
110
100
90
80
70
60
0
10
20
30
40
50
60
70
80
90
100
110
120
Time (minutes)
0 ml/min
225 ml/min
450 ml/min
Arrrows indicate
times when
treadmill was
stopped

FIGURE IX - d.

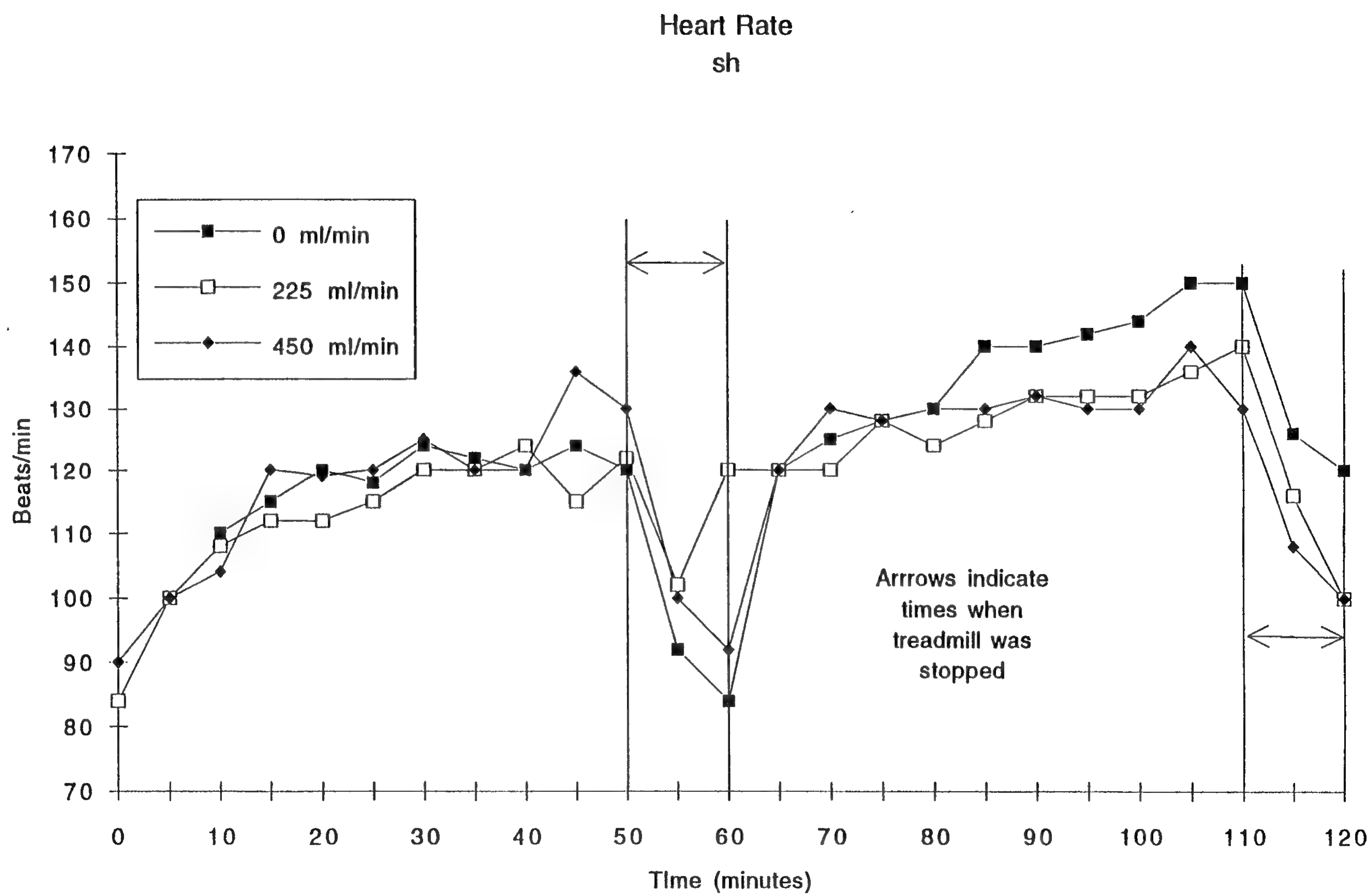

Heart Rate
sh
Beats/min
170
160
150
140
130
120
110
100
90
80
70
0 ml/min
225 ml/min
450 ml/min
Arrrows indicate
times when
treadmill was
stopped
0
10
20
30
40
50
60
70
80
90
100
110
120
TIme (minutes)

FIGURE IX - e.

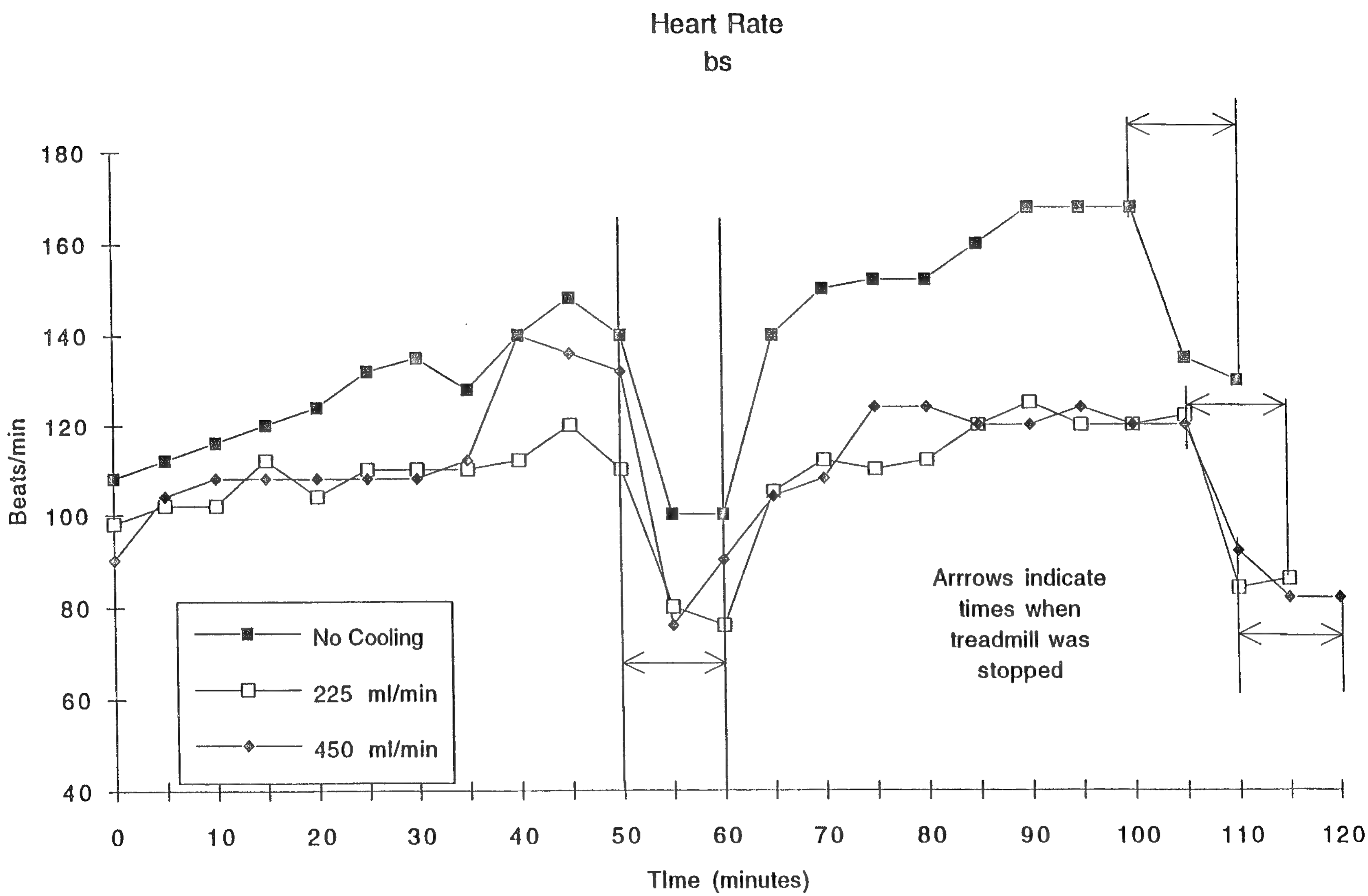
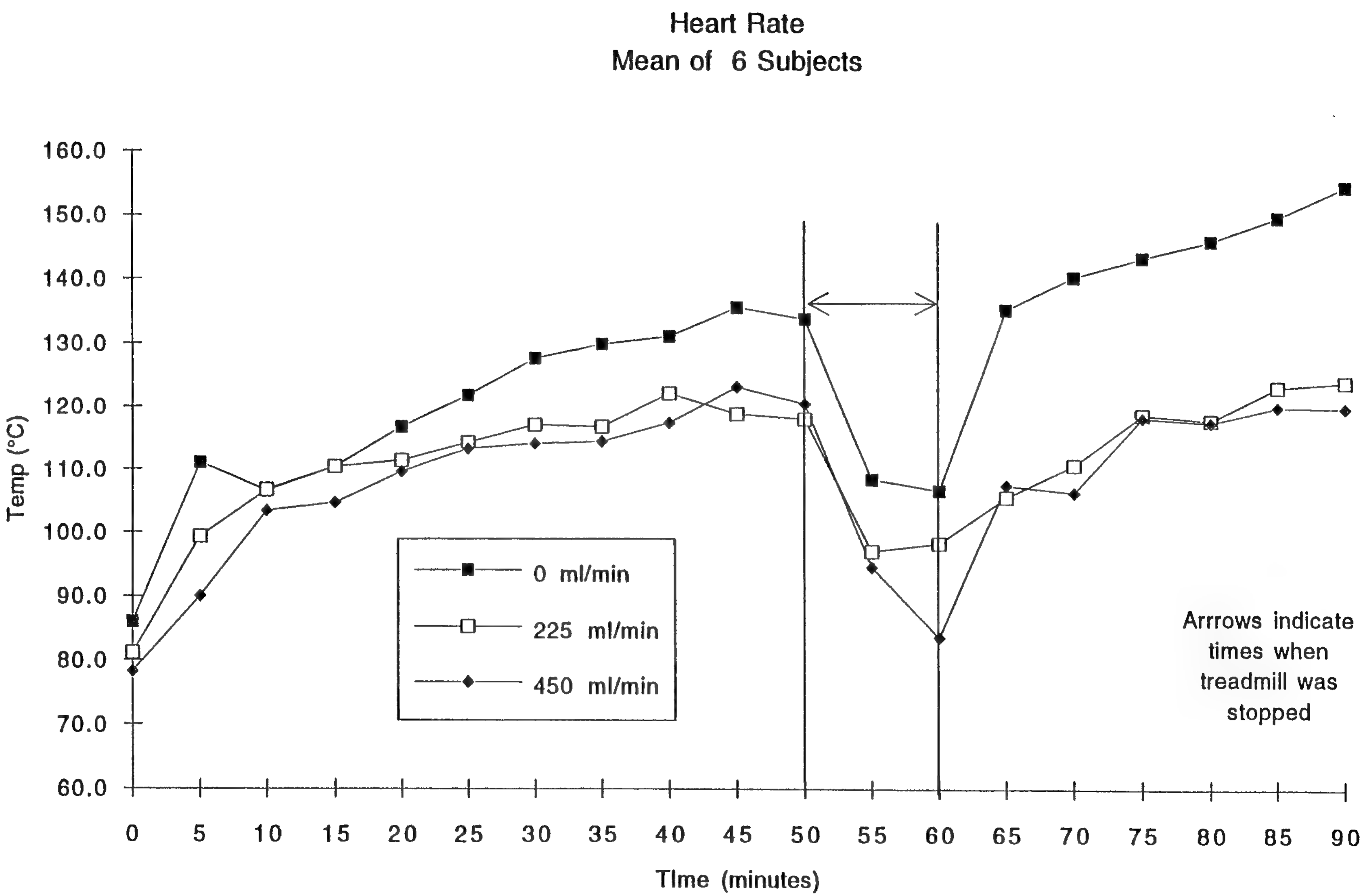

Heart Rate
bs
Beats/min
180
160
140
120
100
80
60
40
0
10
20
30
40
50
60
70
80
90
100
110
120
Time (minutes)
No Cooling
225 ml/min
450 ml/min
Arrrows indicate
times when
treadmill was
stopped

FIGURE IX - f.



Heart Rate
Mean of 6 Subjects
160.0
150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
Temp (°C)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
TIme (minutes)
0 ml/min
225 ml/min
450 ml/min
Arrrows indicate times when treadmill was stopped

FIGURE X.

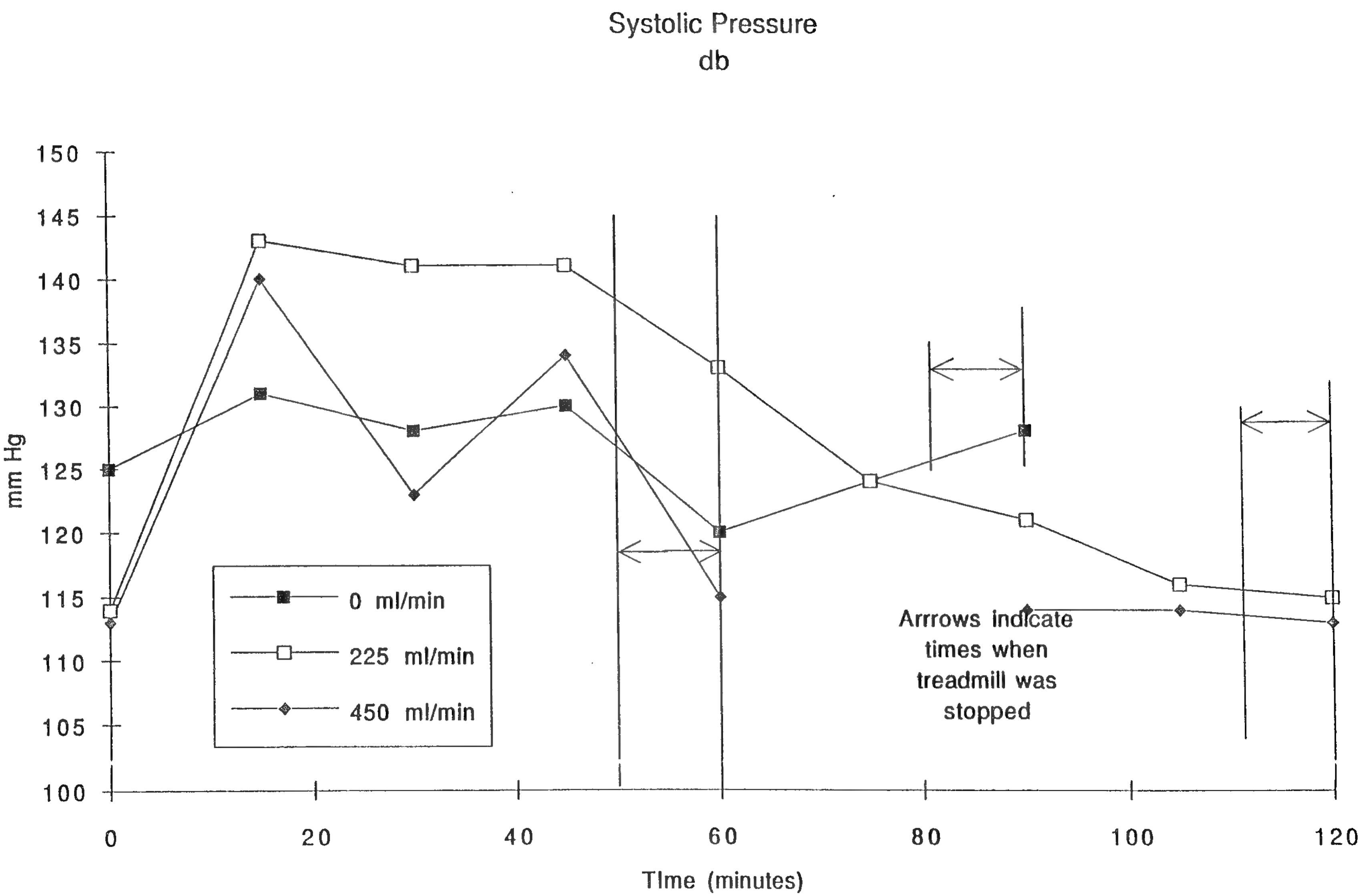

Systolic Pressure
db
mm Hg
150
145
140
135
130
125
120
115
110
105
100
0
20
40
60
80
100
120
TIme (minutes)
0 ml/min
225 ml/min
450 ml/min
Arrrows indicate times when treadmill was stopped

FIGURE XI - a.

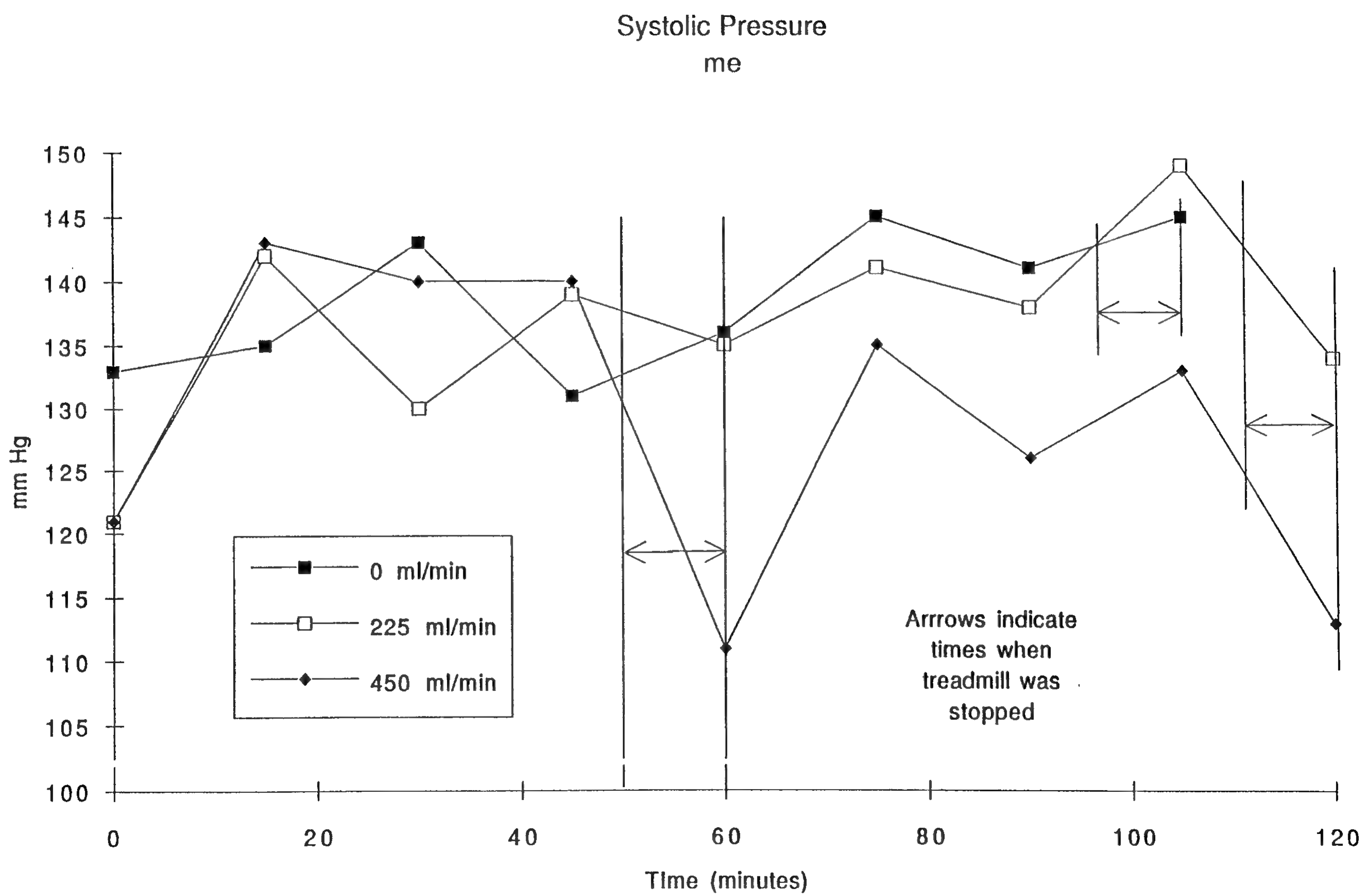

Systolic Pressure
me
mm Hg
150
145
140
135
130
125
120
115
110
105
100
0
20
40
60
80
100
120
Time (minutes)
0 ml/min
225 ml/min
450 ml/min
Arrrows indicate
times when
treadmill was
stopped

FIGURE XI - b.

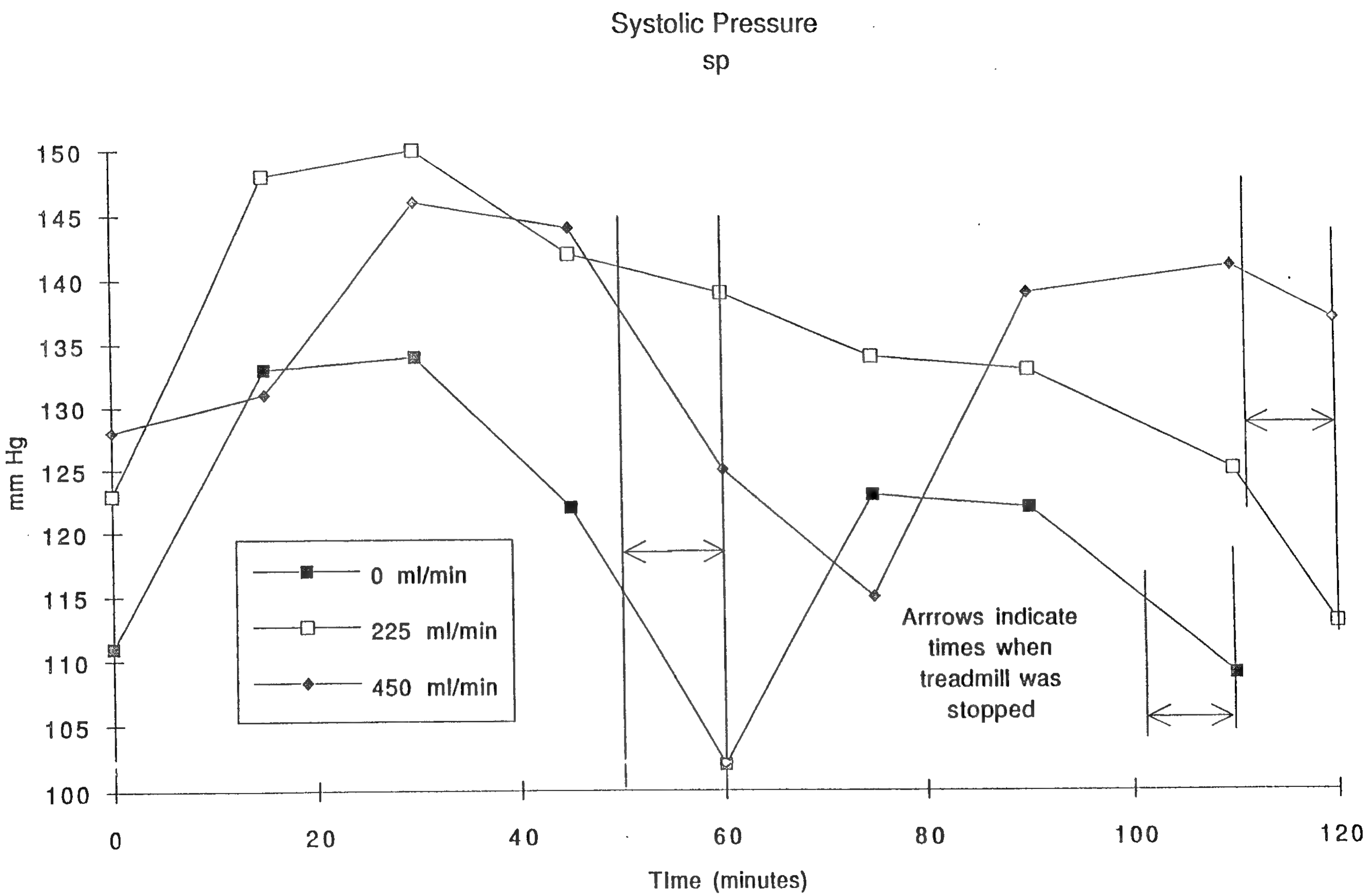
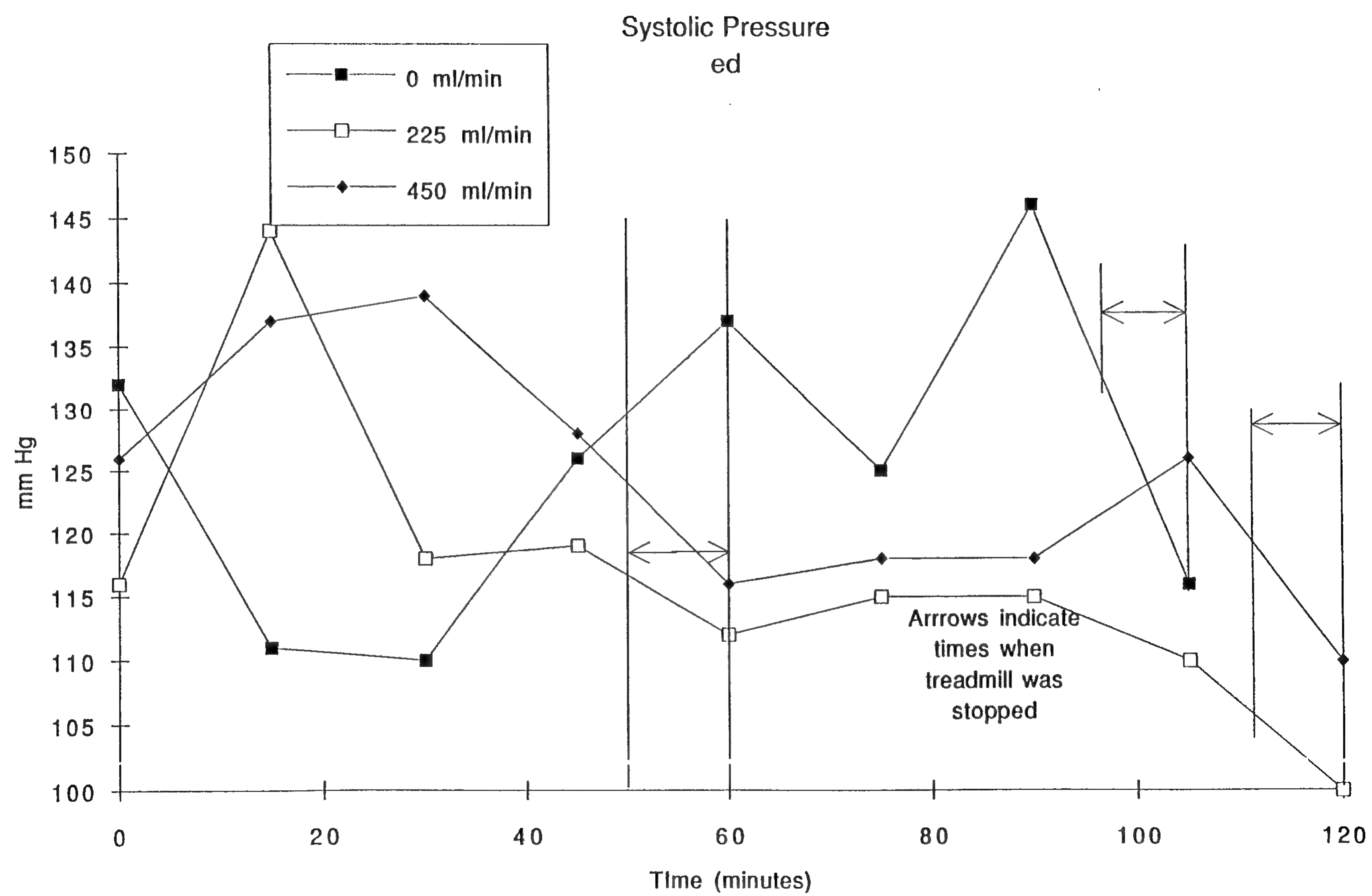
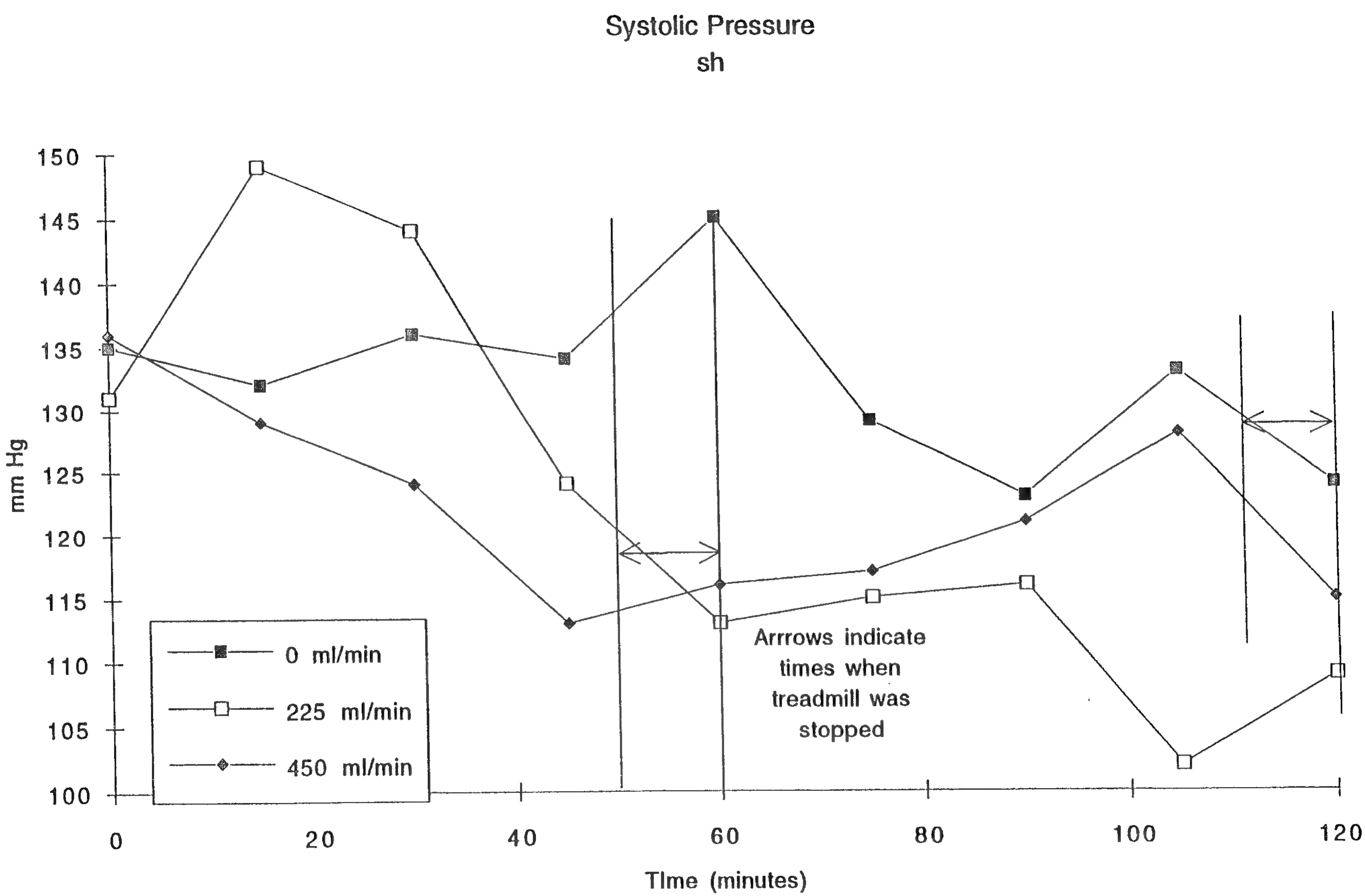

Systolic Pressure
sp
mm Hg
150
145
140
135
130
125
120
115
110
105
100
0
20
40
60
80
100
120
TIme (minutes)
0 ml/min
225 ml/min
450 ml/min
Arrrows indicate
times when
treadmill was
stopped

FIGURE XI - c.



Systolic Pressure
ed
0 ml/min
225 ml/min
450 ml/min
mm Hg
150
145
140
135
130
125
120
115
110
105
100
0
20
40
60
80
100
120
Time (minutes)
Arrrows indicate times when treadmill was stopped

FIGURE XI - d.



Systolic Pressure
sh
150
145
140
135
130
125
120
115
110
105
100
mm Hg
0
20
40
60
80
100
120
TIme (minutes)
0 ml/min
225 ml/min
450 ml/min
Arrrows indicate
times when
treadmill was
stopped

FIGURE XI - e.

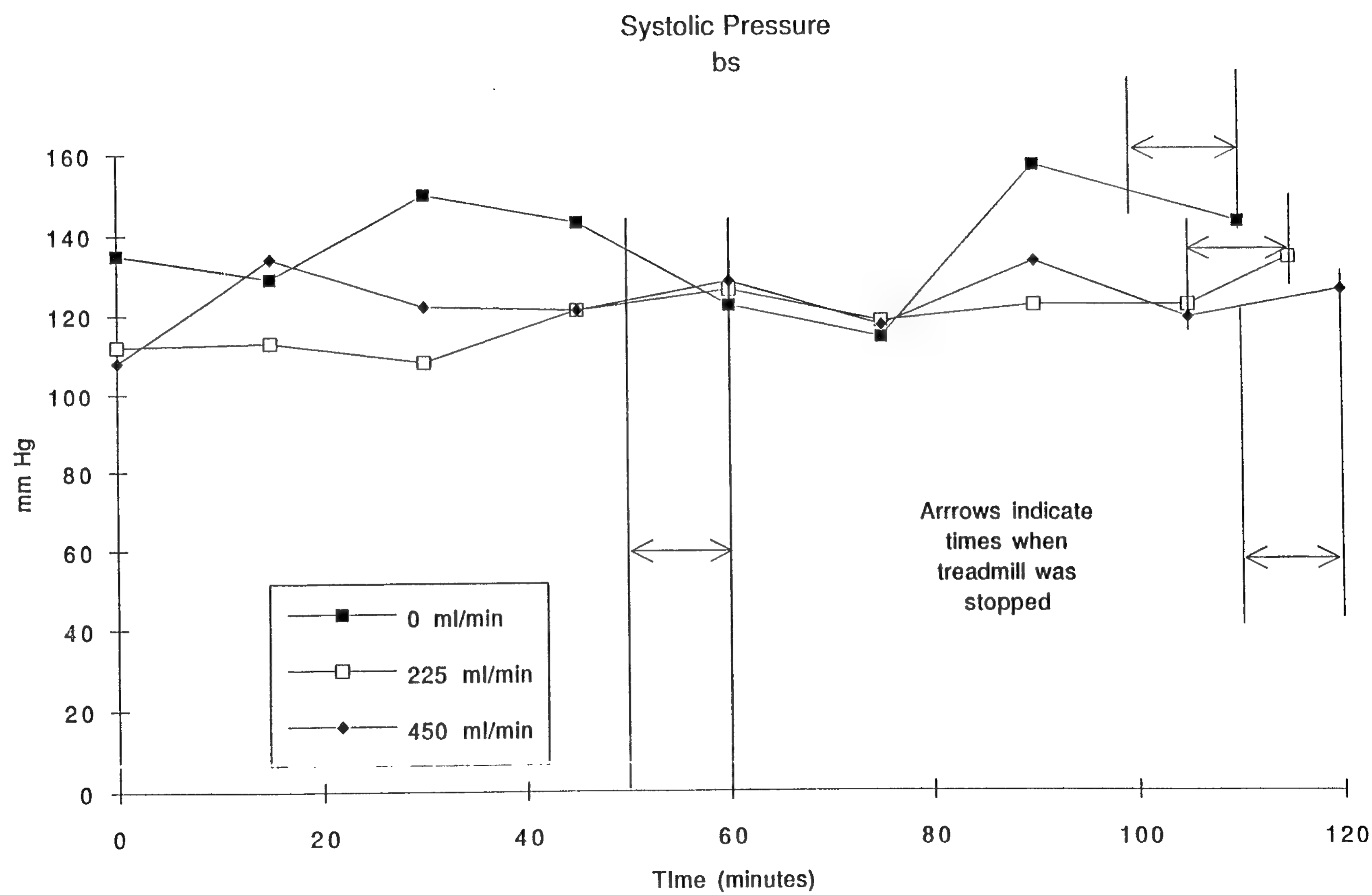
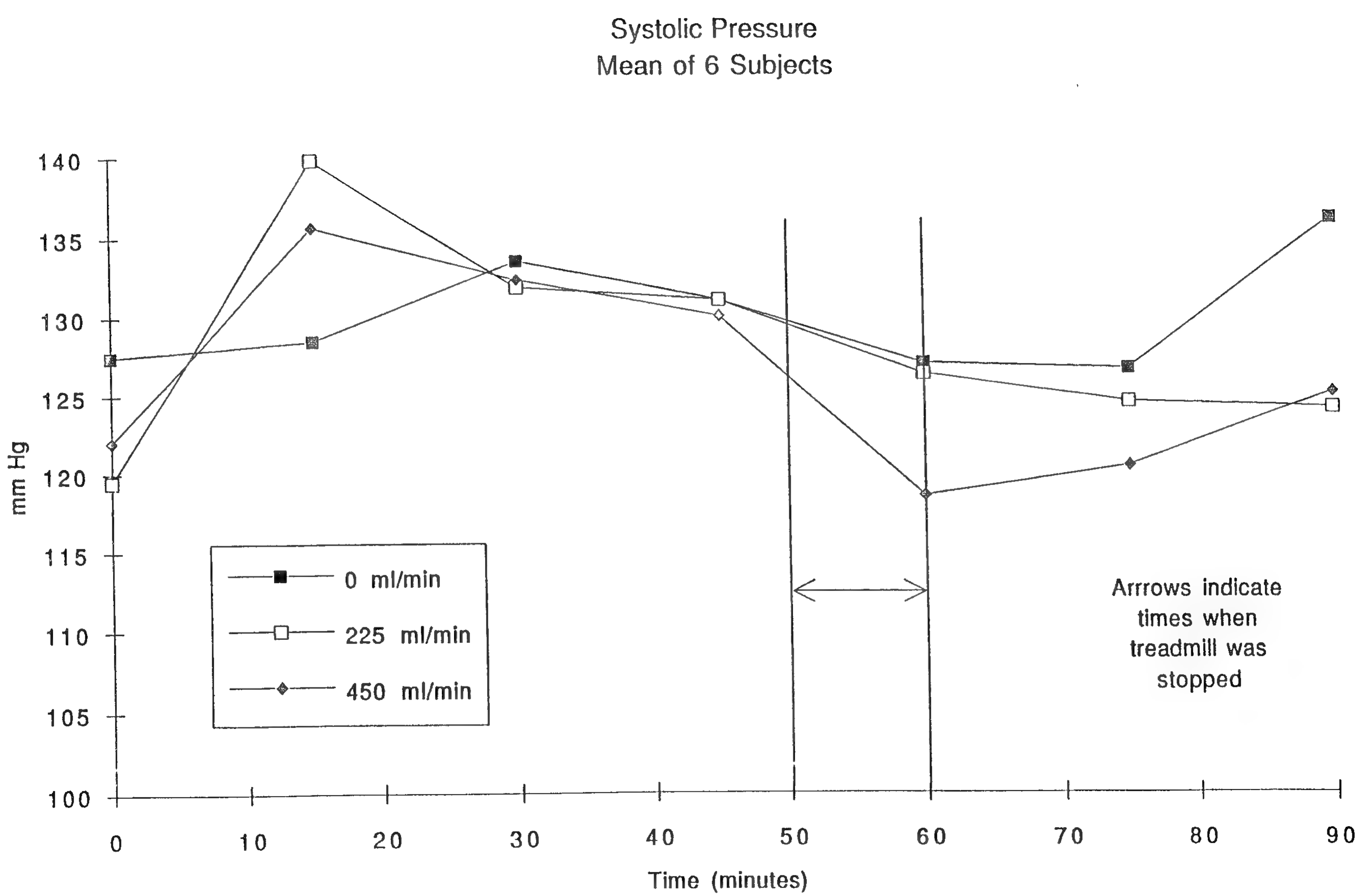

Systolic Pressure
bs
160
140
120
100
80
60
40
20
0
mm Hg
0
20
40
60
80
100
120
Time (minutes)
0 ml/min
225 ml/min
450 ml/min
Arrrows indicate times when treadmill was stopped

FIGURE XI - f.



Systolic Pressure
Mean of 6 Subjects
mm Hg
140
135
130
125
120
115
110
105
100
0
10
20
30
40
50
60
70
80
90
Time (minutes)
0 ml/min
225 ml/min
450 ml/min
Arrows indicate
times when
treadmill was
stopped

FIGURE XII.

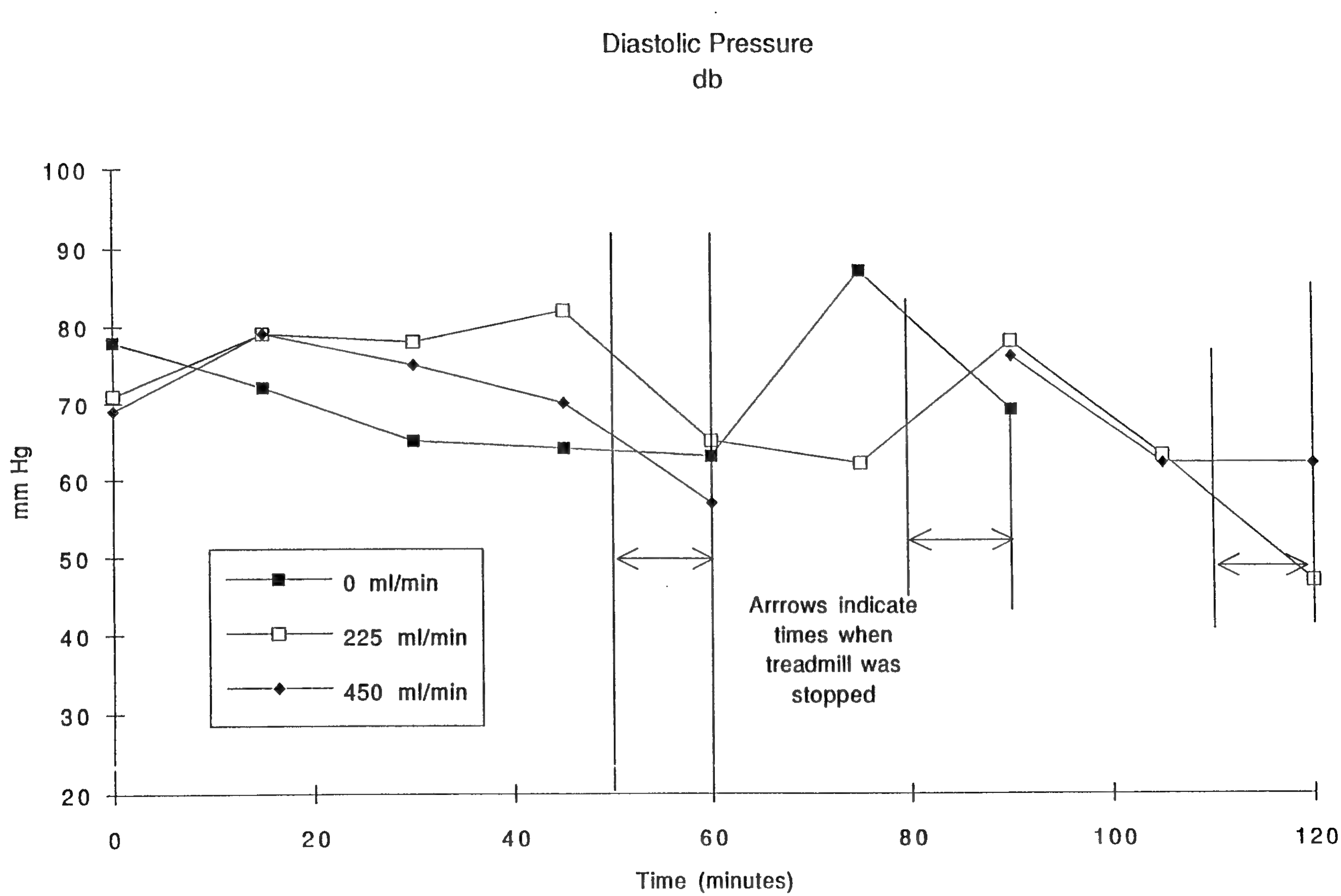


FIGURE XIII - a.

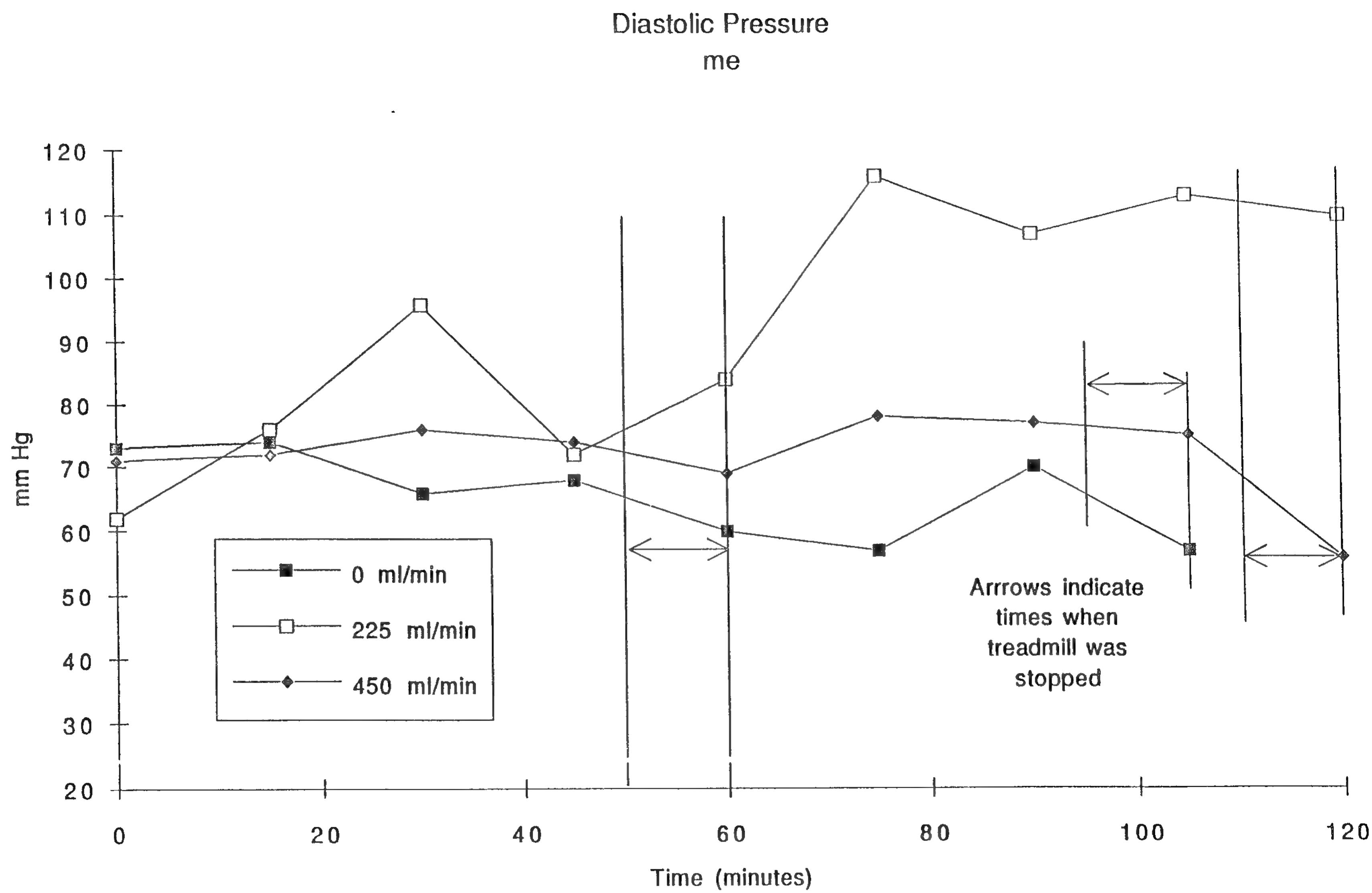


FIGURE XIII - b.

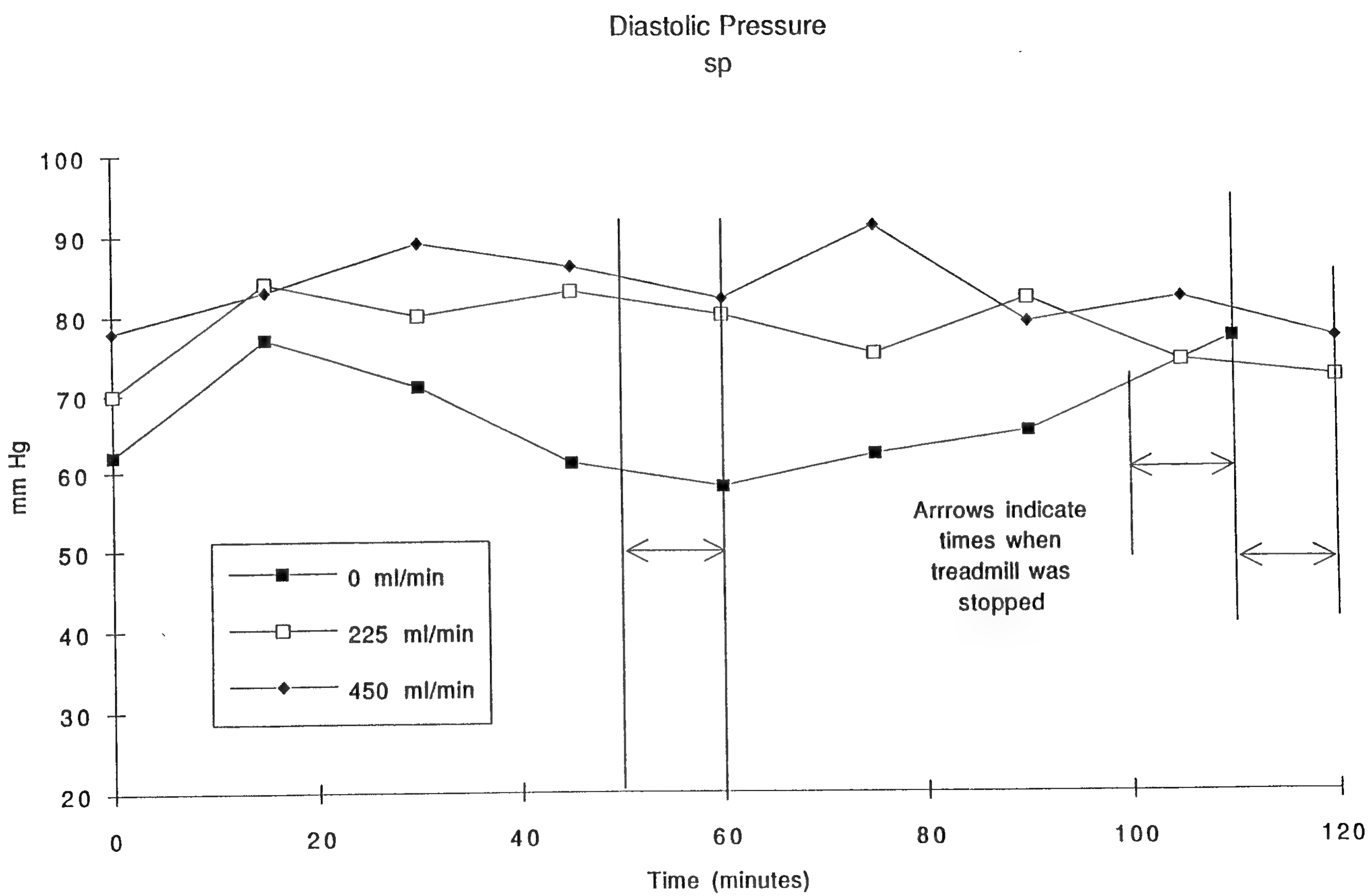


FIGURE XIII - c.

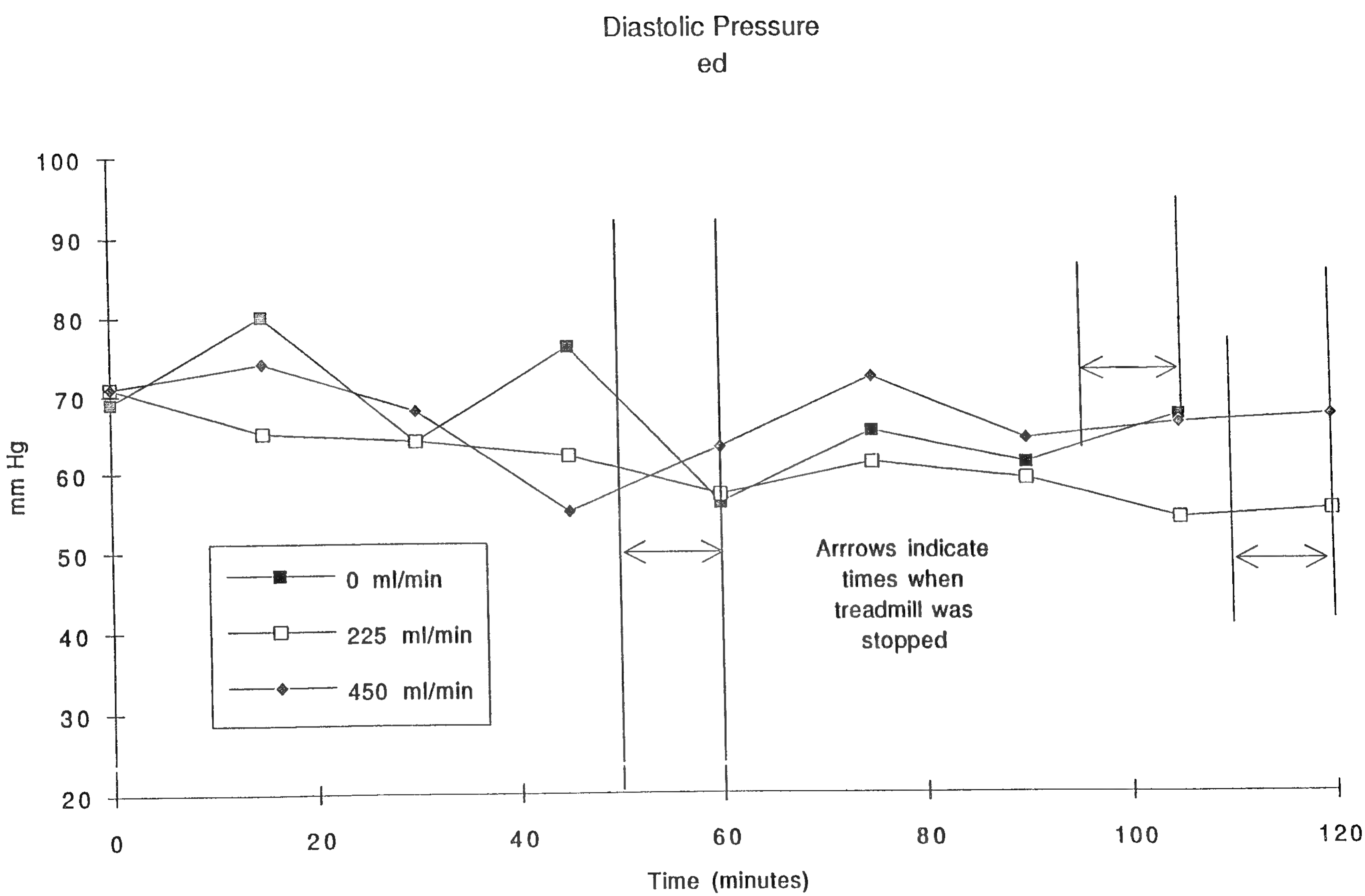


FIGURE XIII - d.

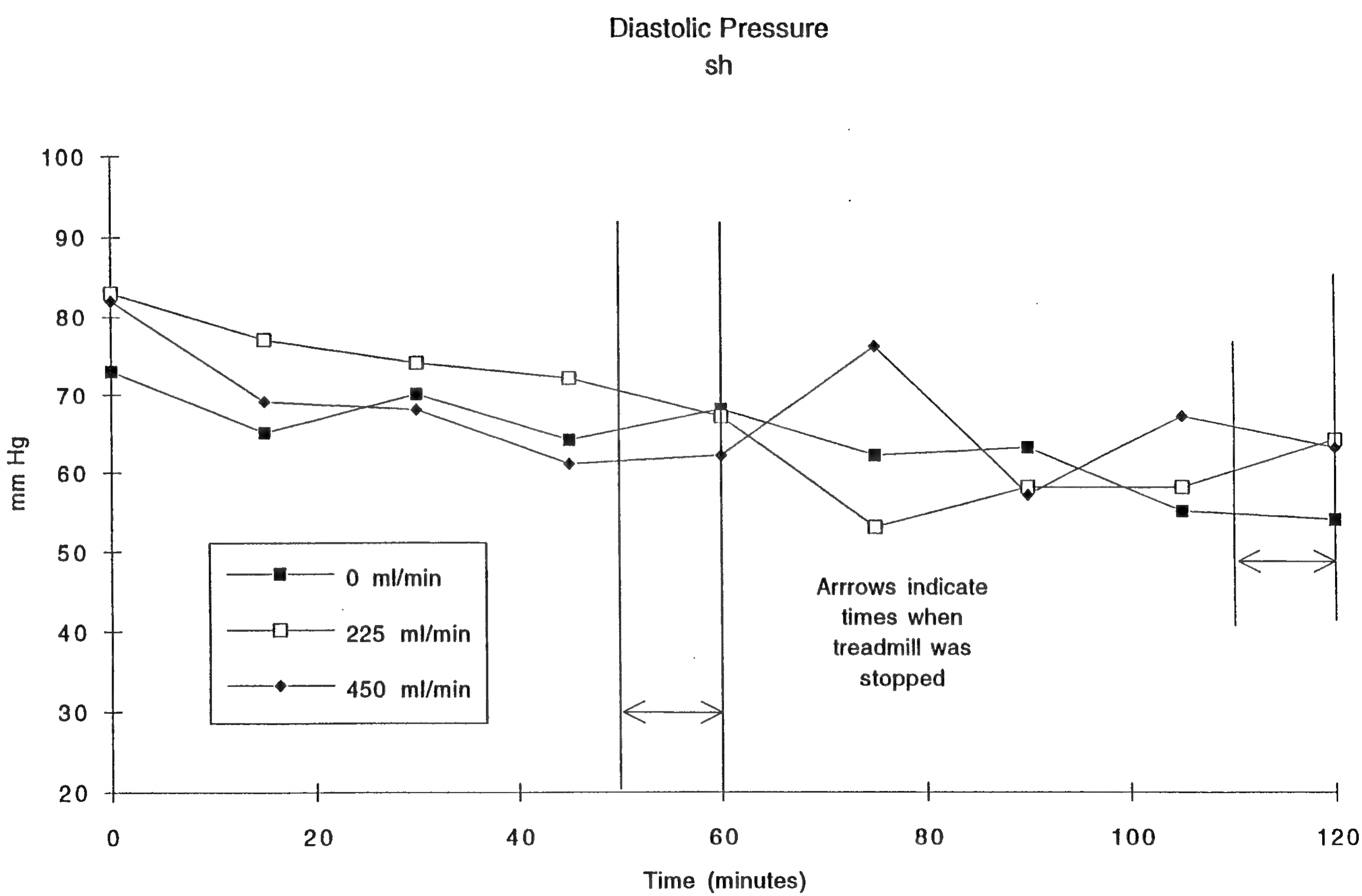


FIGURE XIII - e.

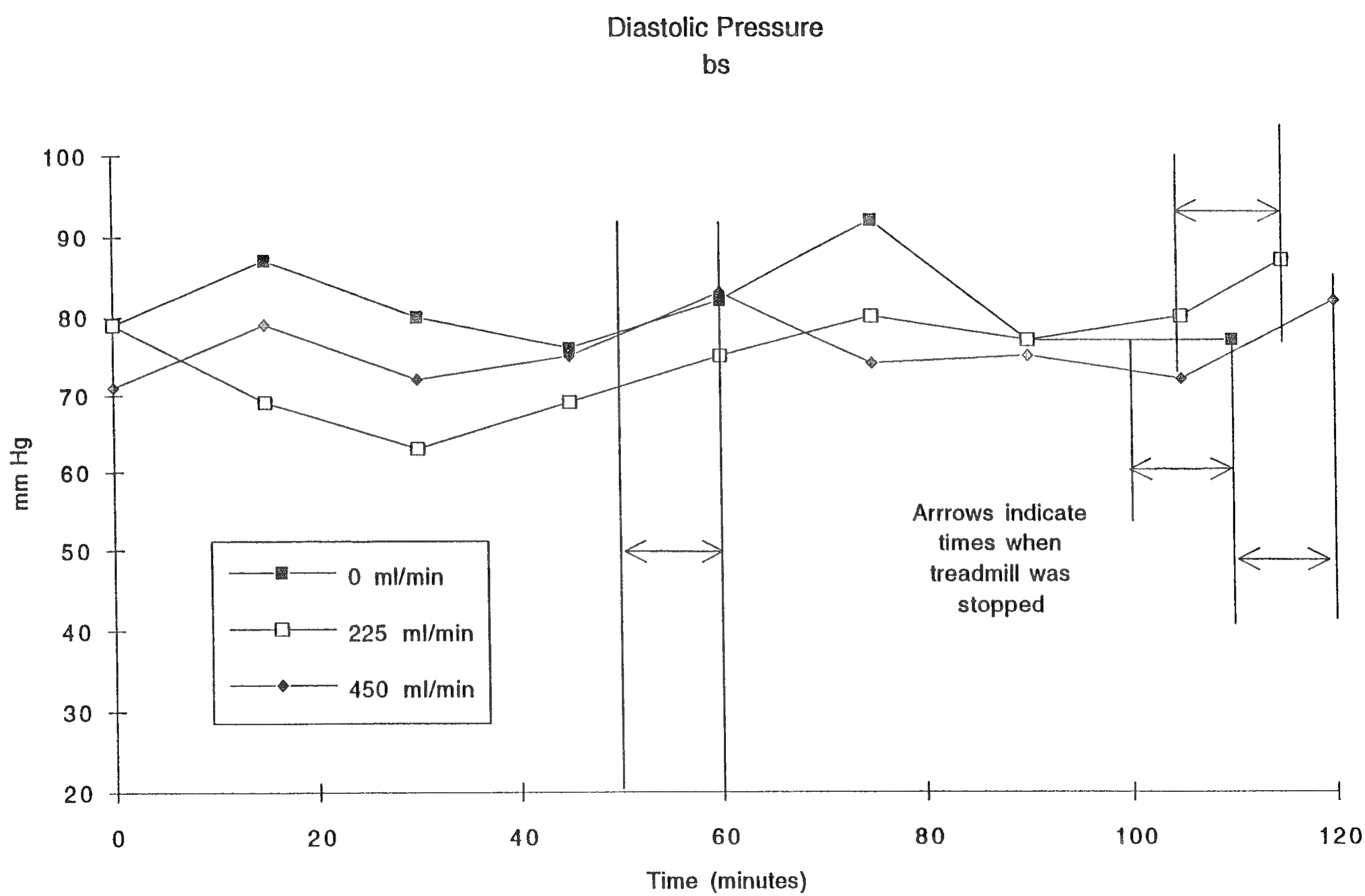


FIGURE XIII - f.

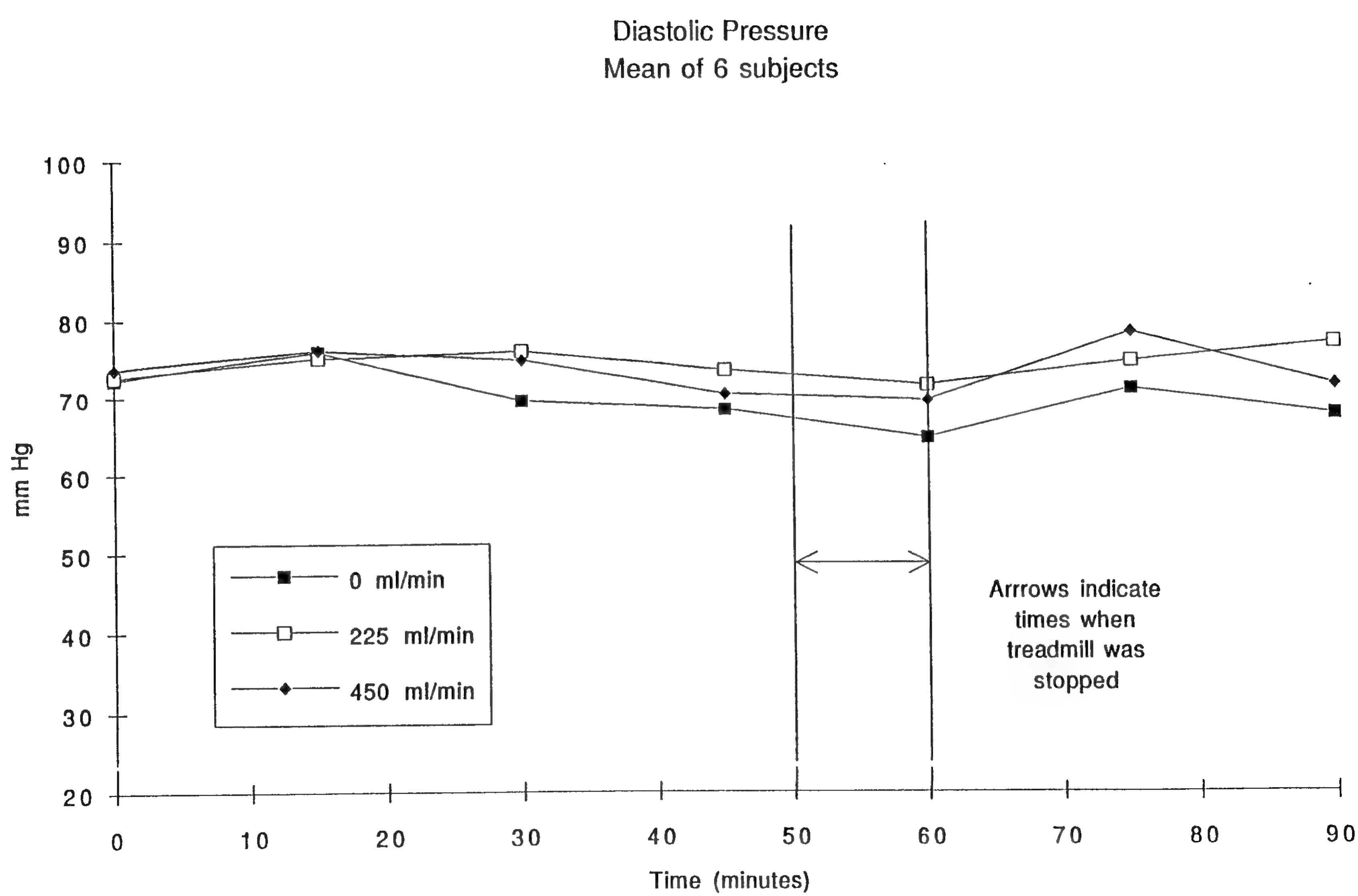

Diastolic Pressure
Mean of 6 subjects
mm Hg
100
90
80
70
60
50
40
30
20
0
10
20
30
40
50
60
70
80
90
Time (minutes)
0 ml/min
225 ml/min
450 ml/min
Arrrows indicate
times when
treadmill was
stopped

FIGURE XIV.

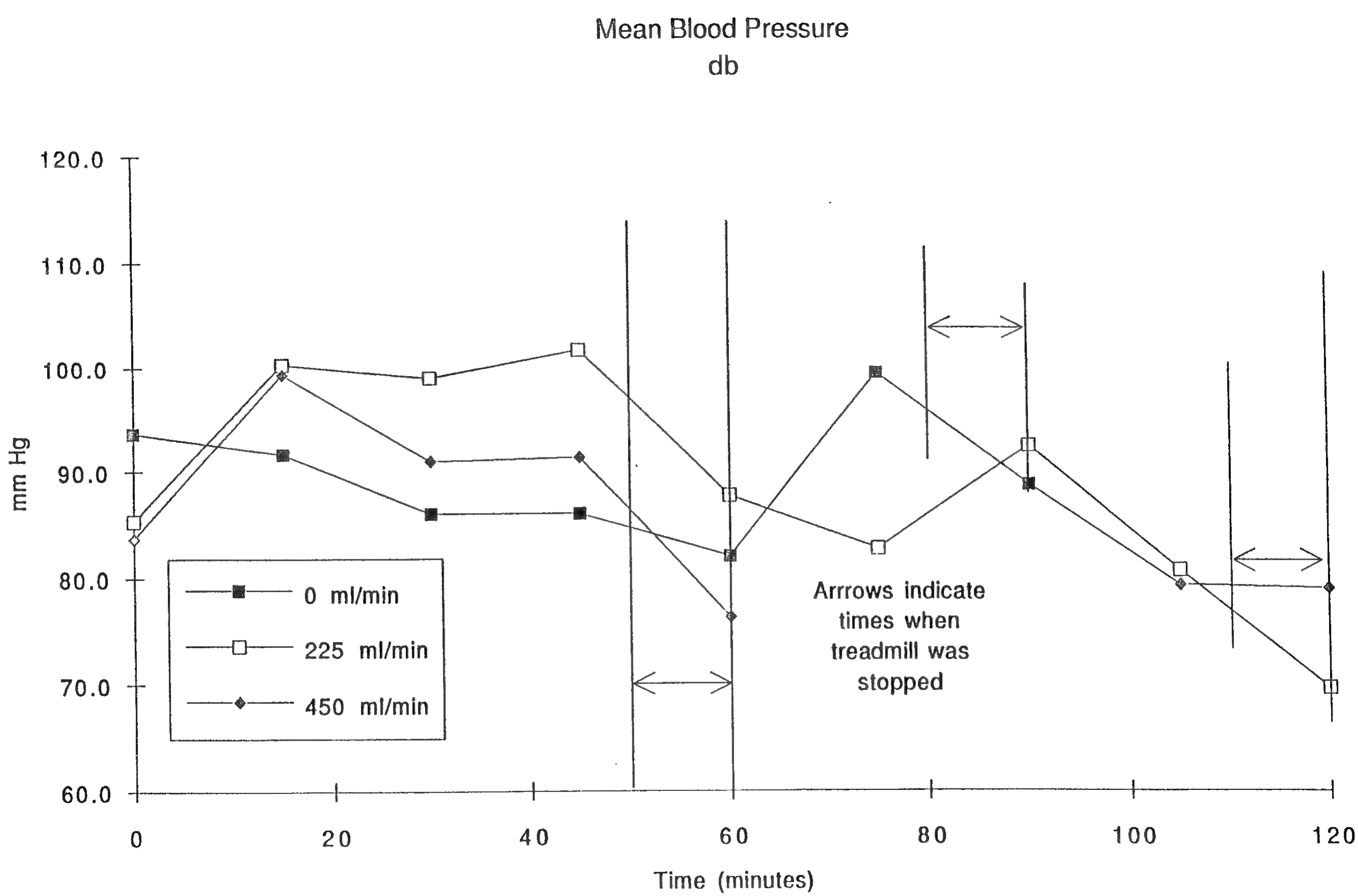
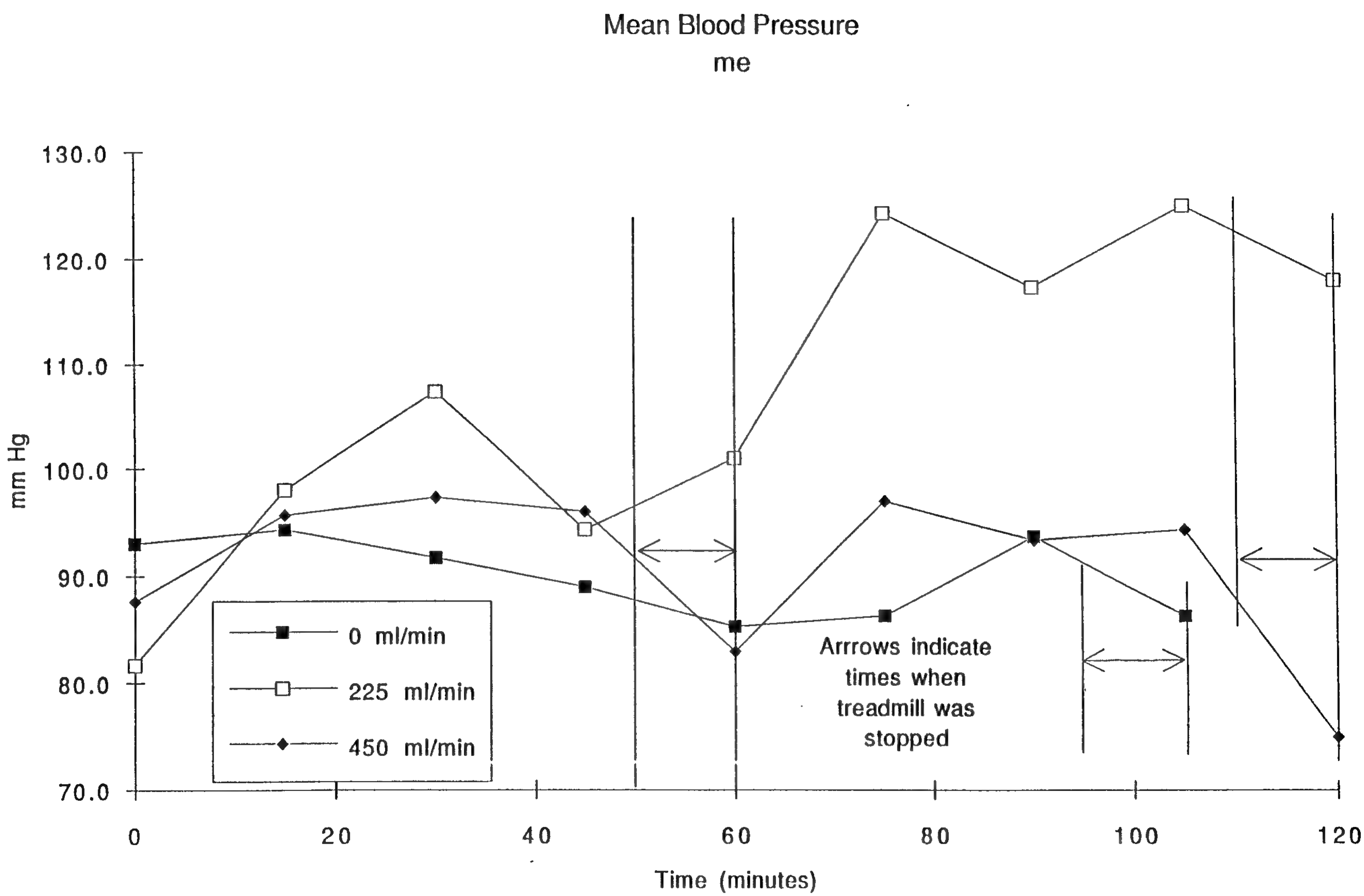

Mean Blood Pressure
db
120.0
110.0
100.0
90.0
80.0
70.0
60.0
mm Hg
0 ml/min
225 ml/min
450 ml/min
Arrrows indicate
times when
treadmill was
stopped
0
20
40
60
80
100
120
Time (minutes)

FIGURE XV - a.



Mean Blood Pressure
me
130.0
120.0
110.0
100.0
90.0
80.0
70.0
mm Hg
0
20
40
60
80
100
120
Time (minutes)
0 ml/min
225 ml/min
450 ml/min
Arrrows indicate times when treadmill was stopped

FIGURE XV - b.

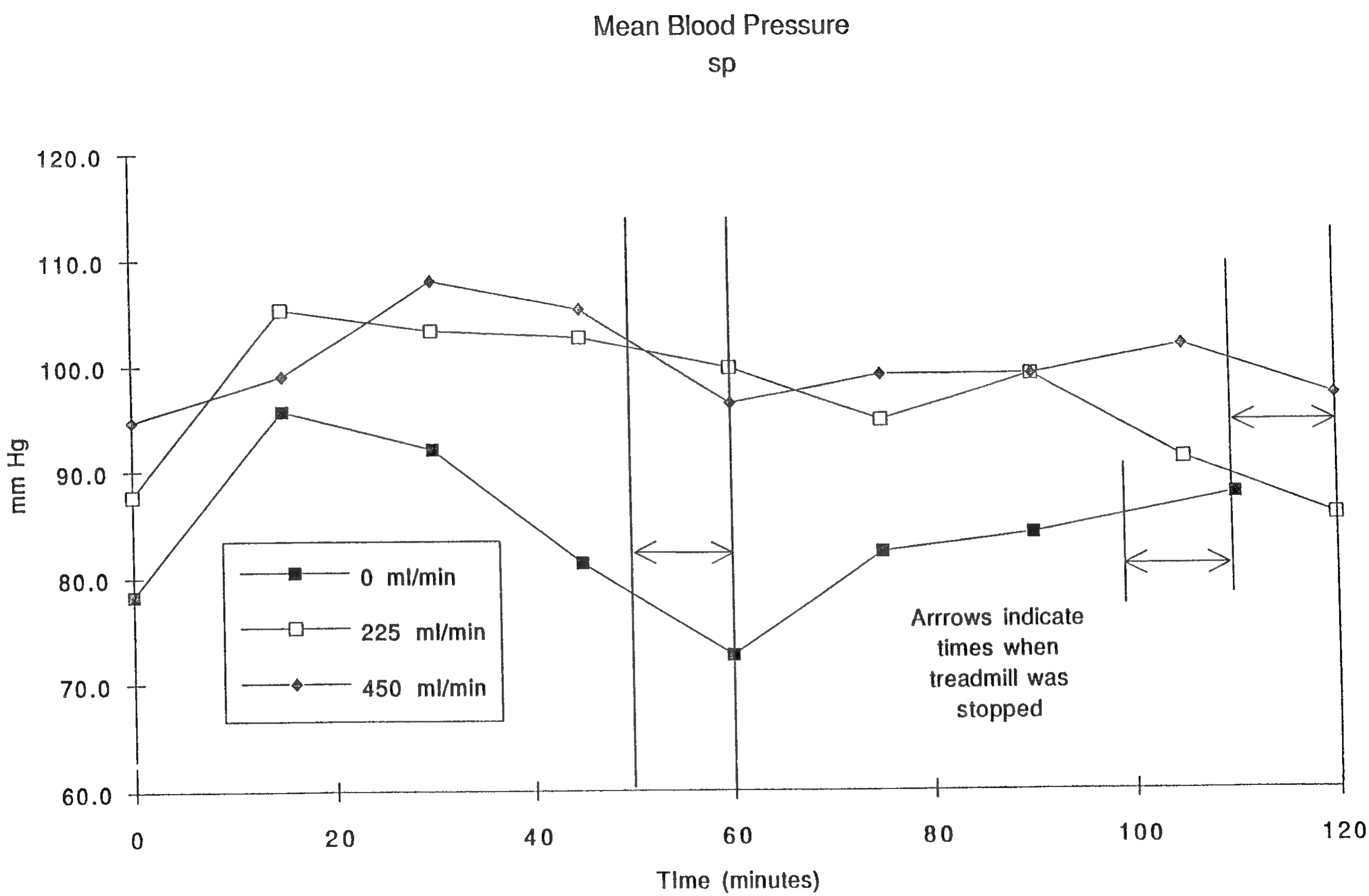

Mean Blood Pressure
sp
120.0
110.0
100.0
90.0
80.0
70.0
60.0
mm Hg
0 ml/min
225 ml/min
450 ml/min
Arrrows indicate
times when
treadmill was
stopped
0
20
40
60
80
100
120
TIme (minutes)

FIGURE XV - c.

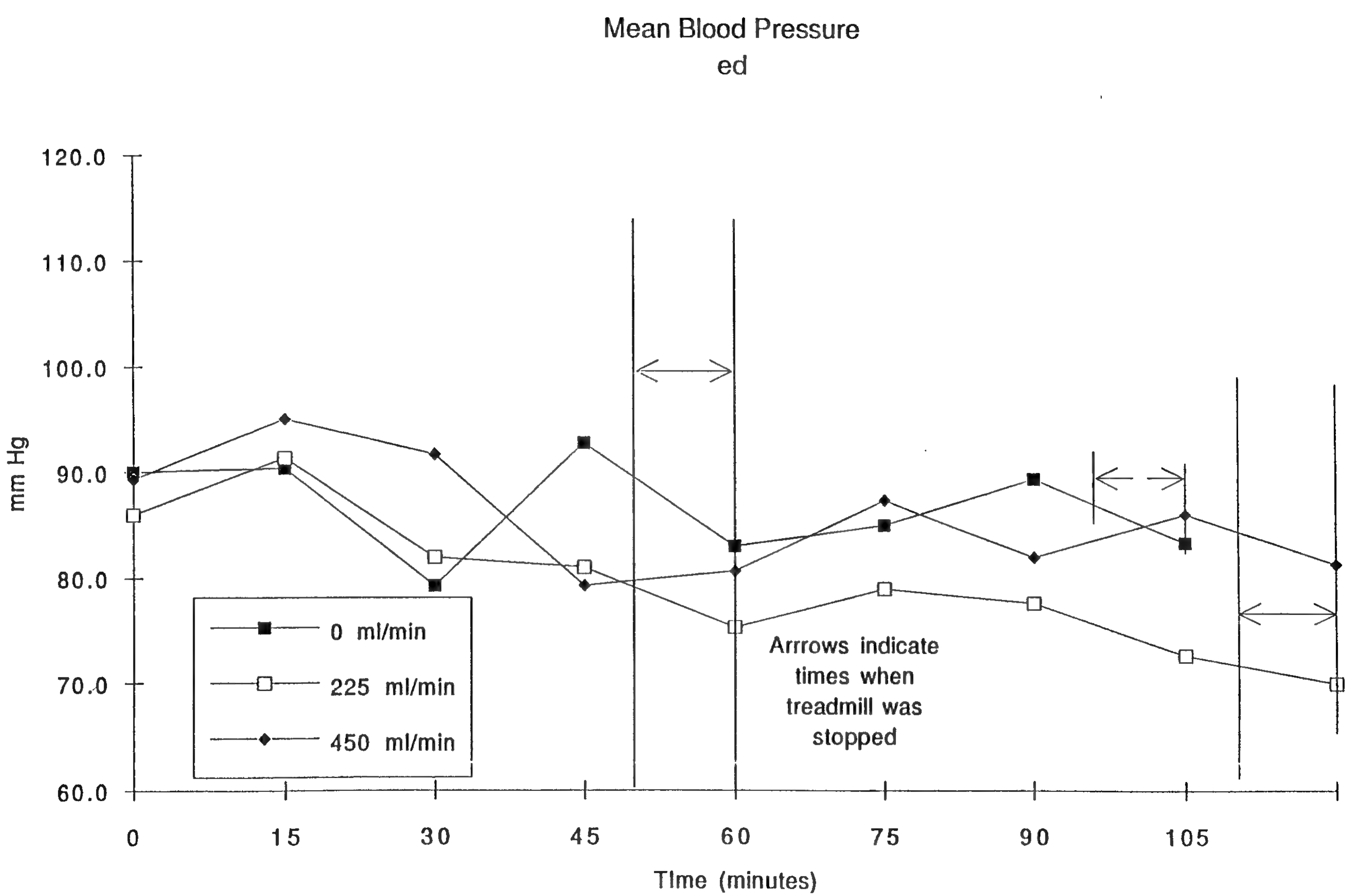

Mean Blood Pressure
ed
120.0
110.0
100.0
90.0
80.0
70.0
60.0
mm Hg
0 ml/min
225 ml/min
450 ml/min
Arrrows indicate
times when
treadmill was
stopped
0
15
30
45
60
75
90
105
TIme (minutes)

FIGURE XV - d.

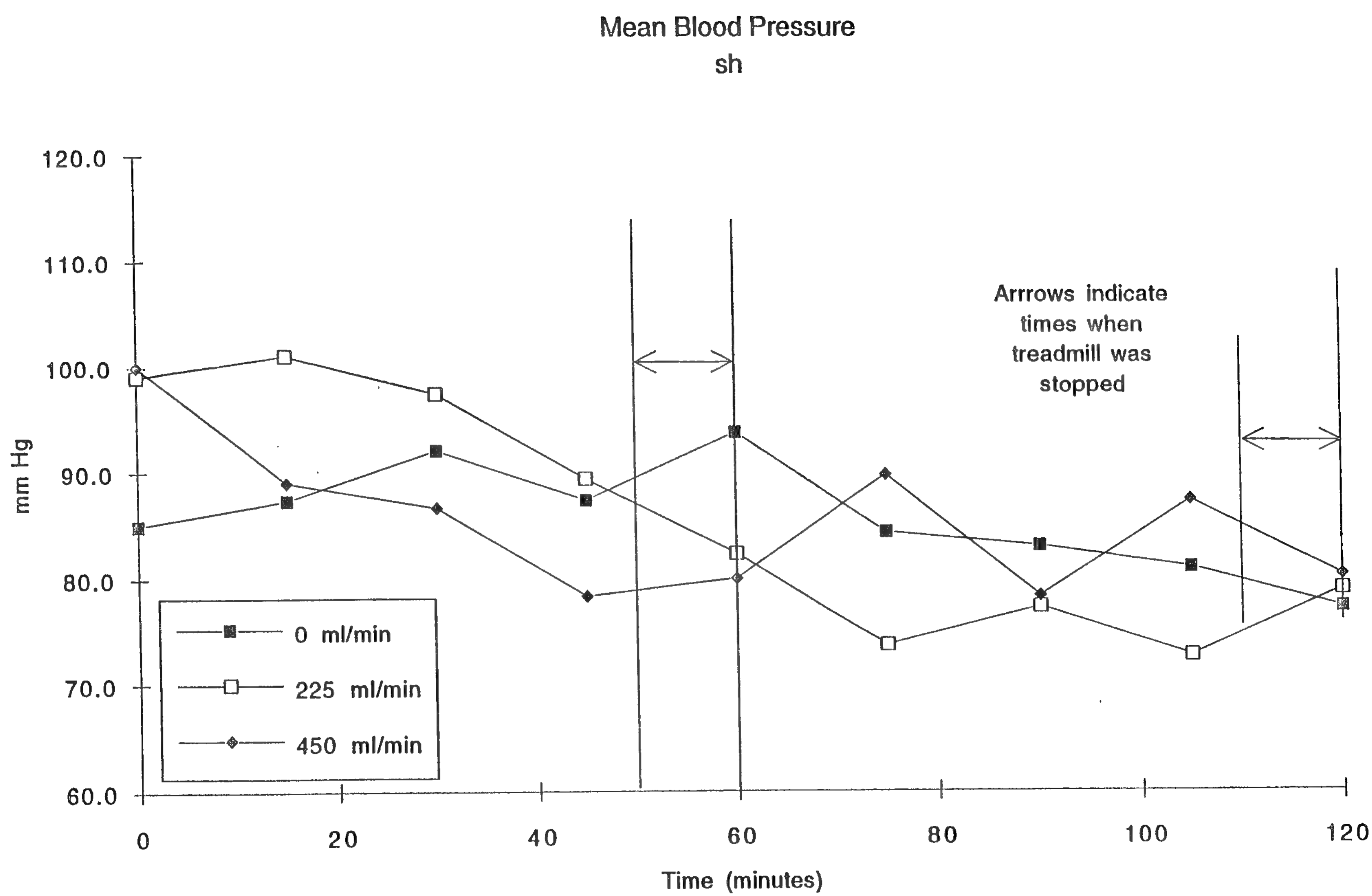

Mean Blood Pressure
sh
mm Hg
120.0
110.0
100.0
90.0
80.0
70.0
60.0
0
20
40
60
80
100
120
Time (minutes)
0 ml/min
225 ml/min
450 ml/min
Arrrows indicate
times when
treadmill was
stopped

FIGURE XV - e.

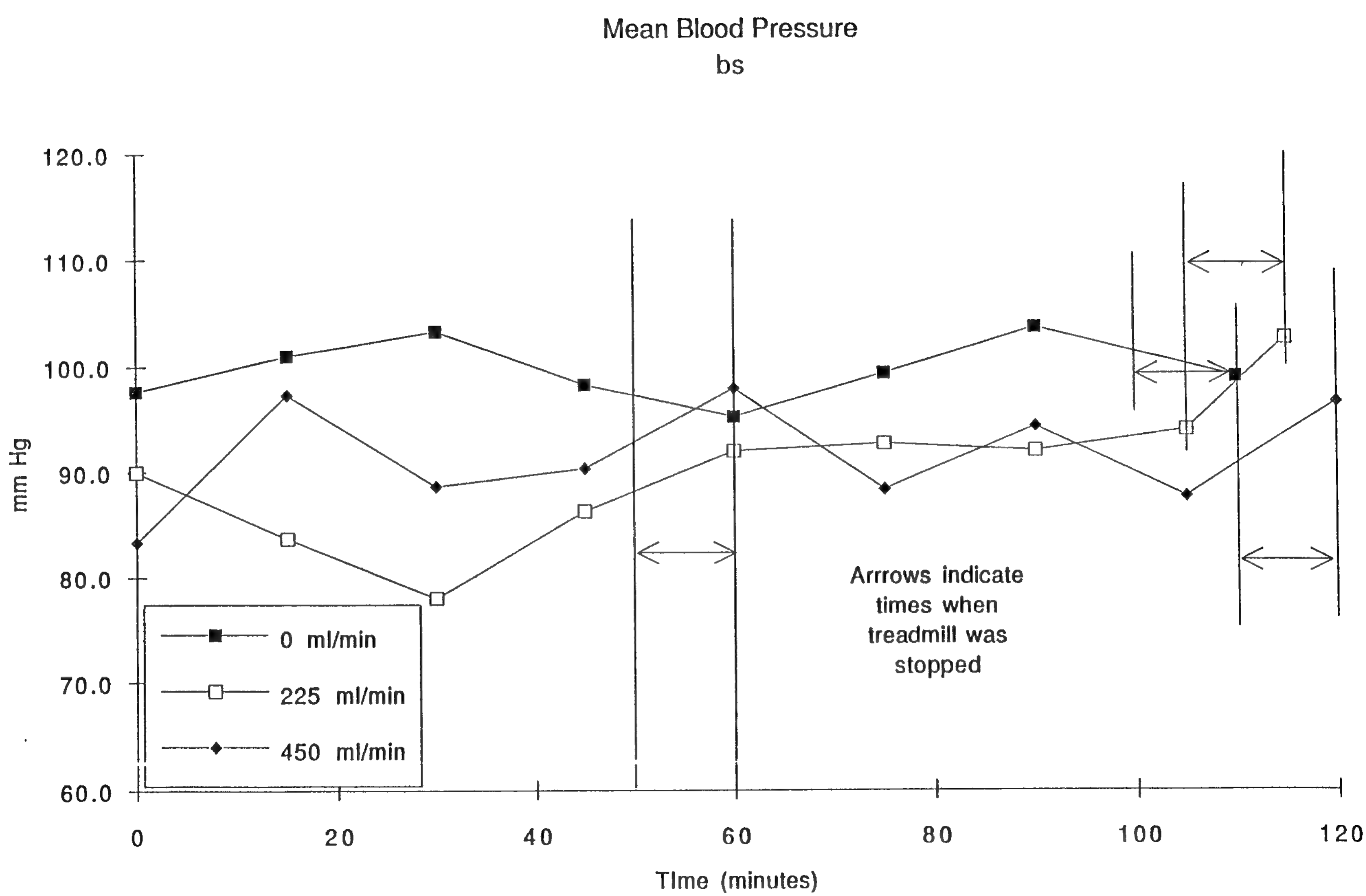

Mean Blood Pressure
bs
120.0
110.0
100.0
90.0
80.0
70.0
60.0
mm Hg
0 ml/min
225 ml/min
450 ml/min
Arrrows indicate
times when
treadmill was
stopped
0
20
40
60
80
100
120
TIme (minutes)

FIGURE XV - f.

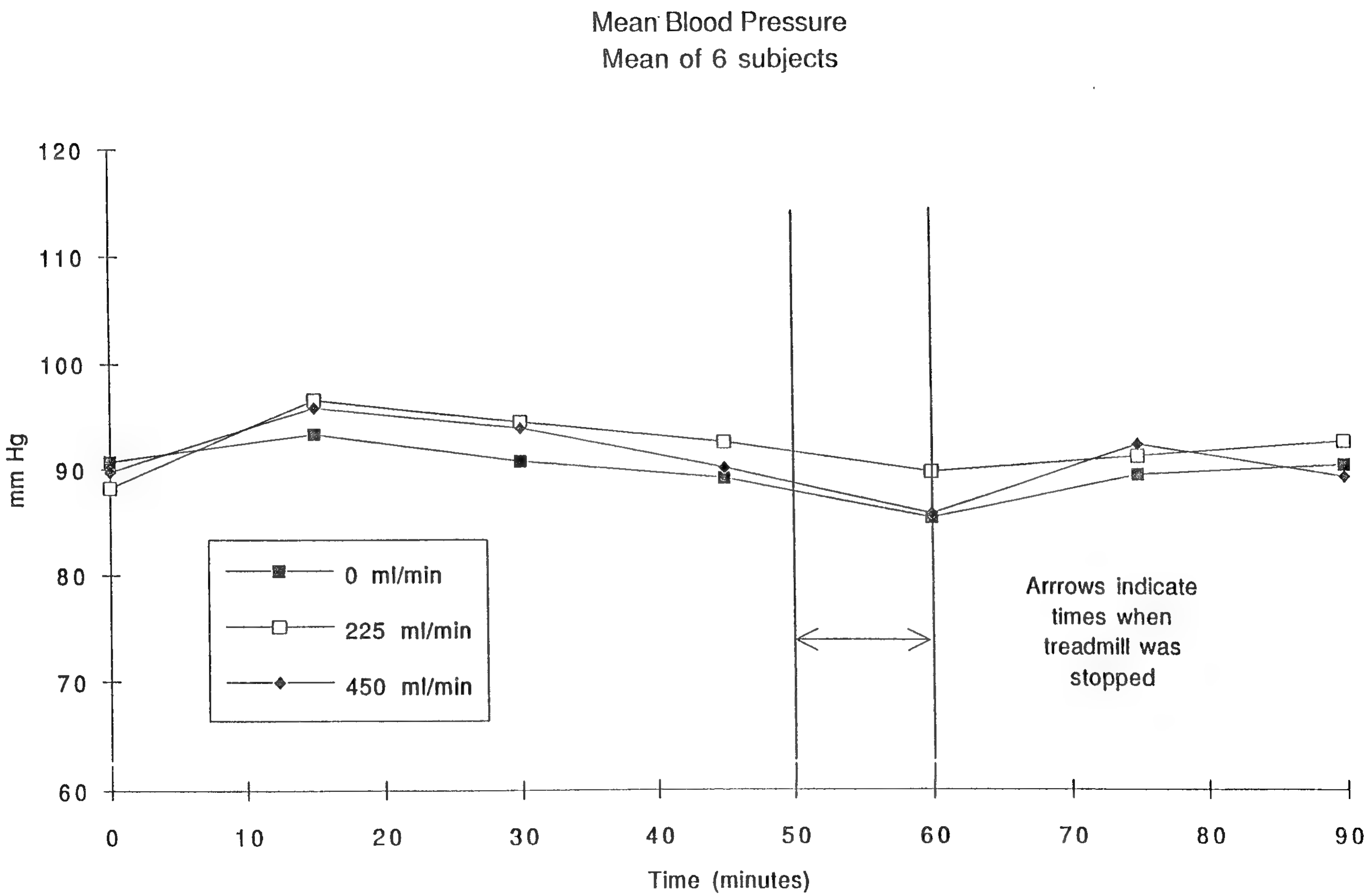

Mean Blood Pressure
Mean of 6 subjects
120
110
100
90
80
70
60
mm Hg
0 ml/min
225 ml/min
450 ml/min
Arrrows indicate
times when
treadmill was
stopped
0
10
20
30
40
50
60
70
80
90
Time (minutes)

FIGURE XVI.

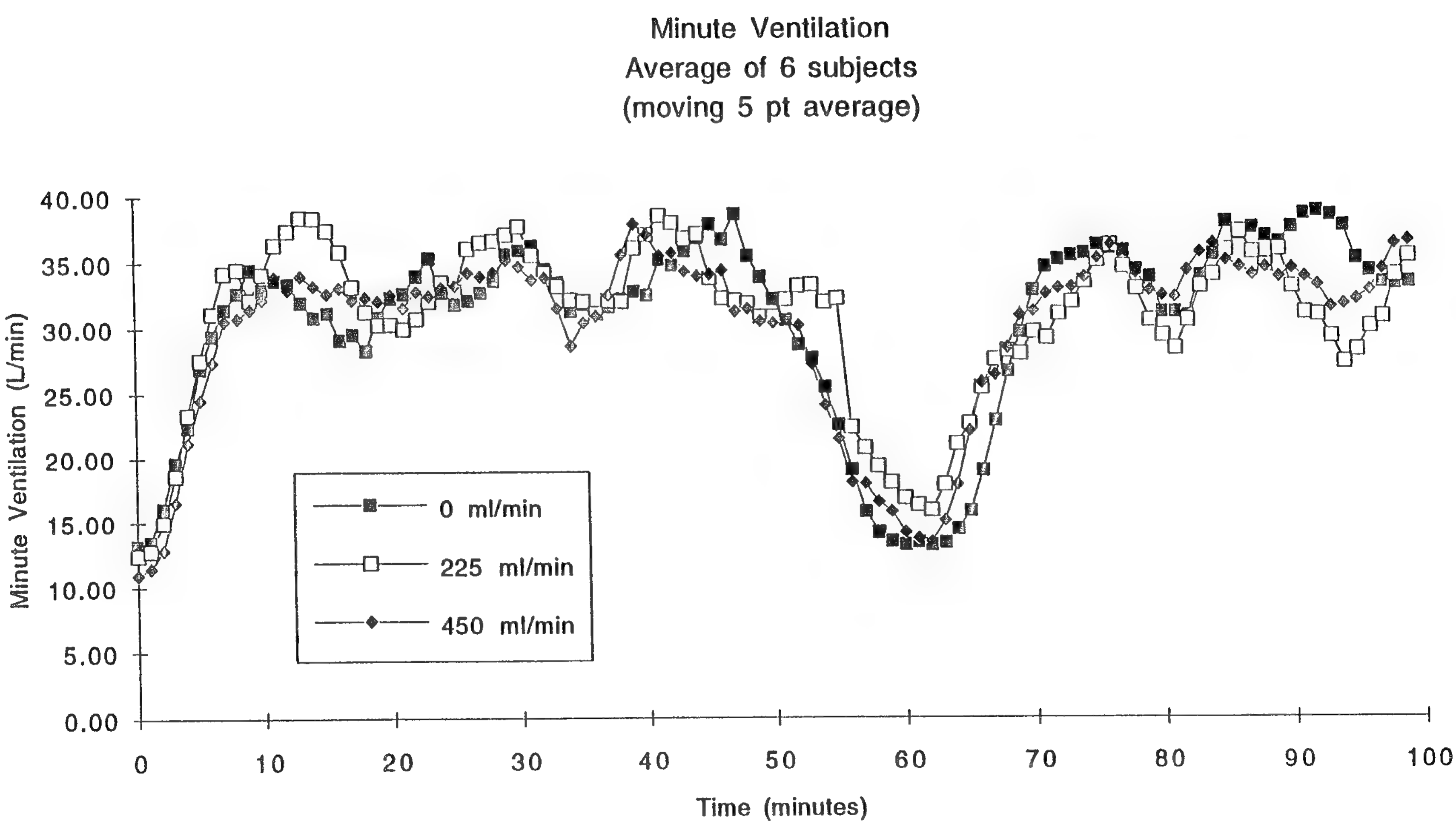
Respiratory Parameters:

Time dependent changes in minute ventilation, oxygen consumption, and respiratory rate (mean for all 6 subjects) for the three experimental conditions, are presented in Figures XVII, XVIII, and XIX. There are no significant differences between conditions and no changes over time with the exception of the expected decrease in these parameters during the 10-min rest period from minute 50 to minute 60.

Fluid Balance Parameters:

Time averaged urine flows (collected volume/time) were determined prior to and at the end of the experiment. Figure XX summarizes these results. Under all conditions the urine flow decreased during the heat exposure-exercise period, and the addition of cooling did not alter the magnitude of this decrease.

To estimate the magnitude of water loss due to sweating, the subjects were weighed before donning the clothing prior to the experiment. At the end of the experiment, all clothing and instrumentation was removed and the subjects were weighed. The percent loss of body weight was calculated and is presented in Figure XXI. In the control/no cooling condition the subjects lost 2% of their body weight during the experiment. In those conditions in which cooling was present, the loss in body weight decreased to 1.7% during the moderate cooling and decreased to 1.4% during the maximum cooling. Statistical comparisons of the three conditions show that only the difference in weight loss between the no cool condition and the maximum cool condition was significantly different at the $p < 0.05$ level.



Minute Ventilation
Average of 6 subjects
(moving 5 pt average)
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Minute Ventilation (L/min)
0 ml/min
225 ml/min
450 ml/min
0
10
20
30
40
50
60
70
80
90
100
Time (minutes)

FIGURE XVII.

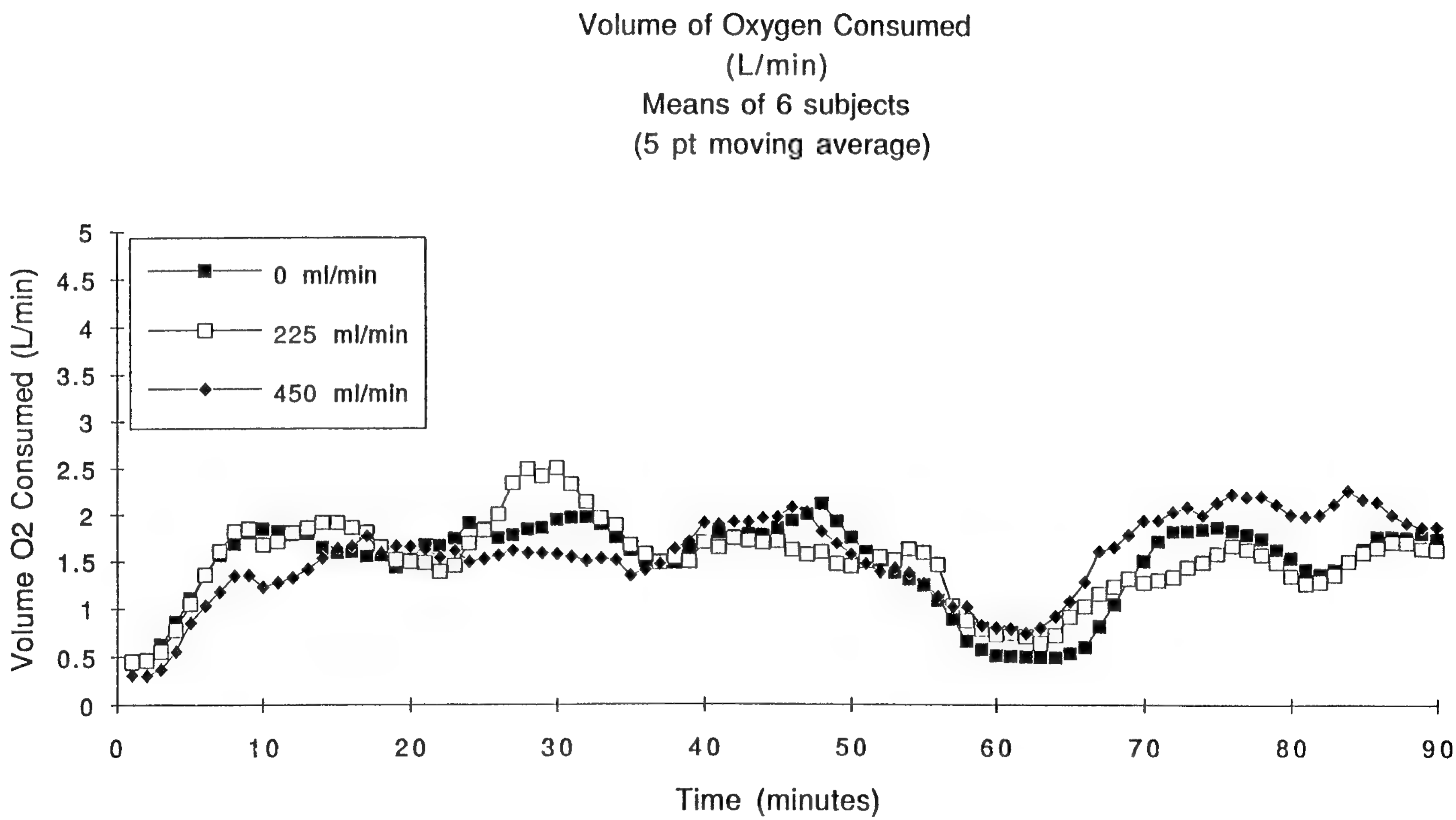


FIGURE XVIII.

2/23/9310:33 AM

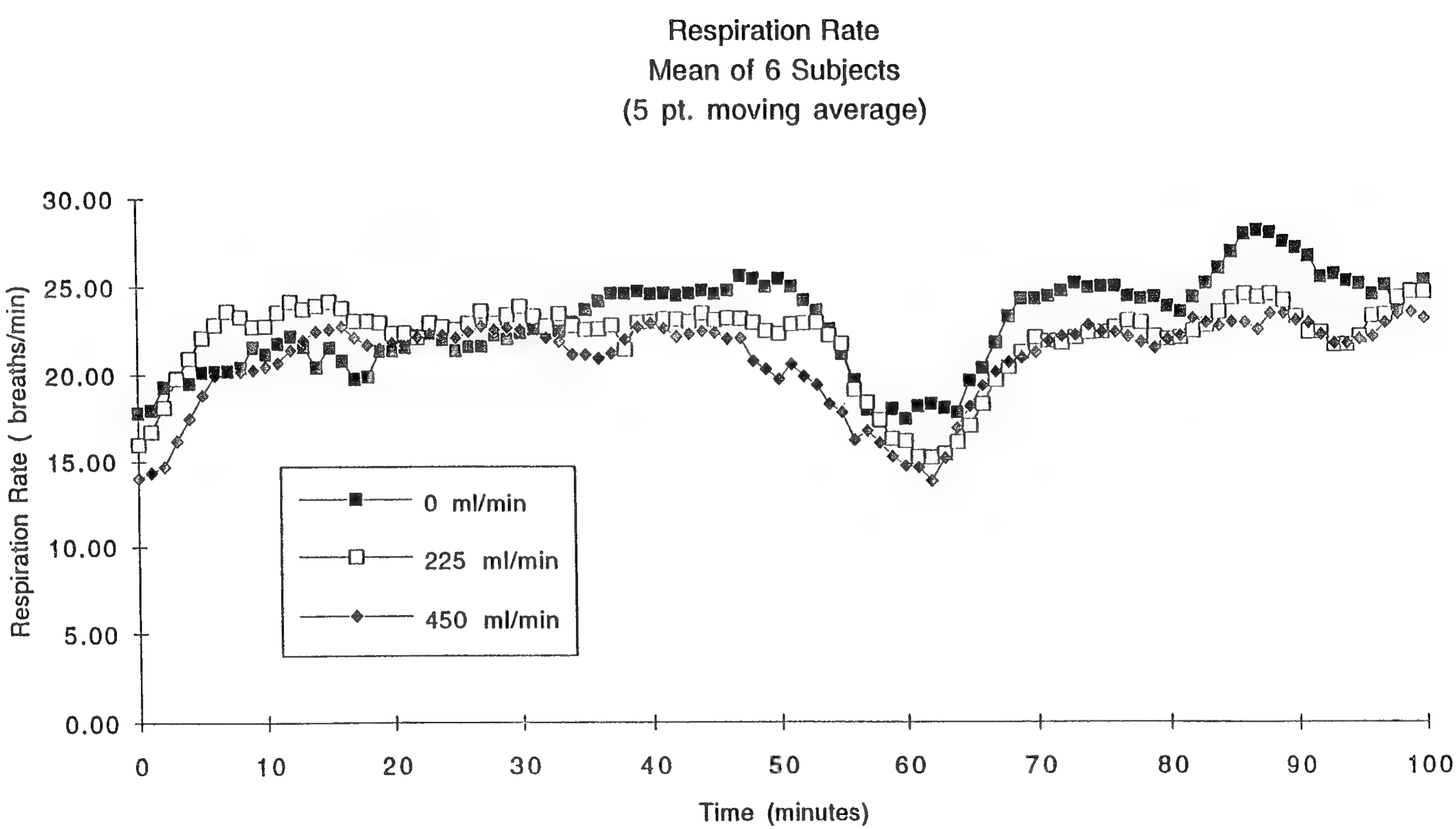
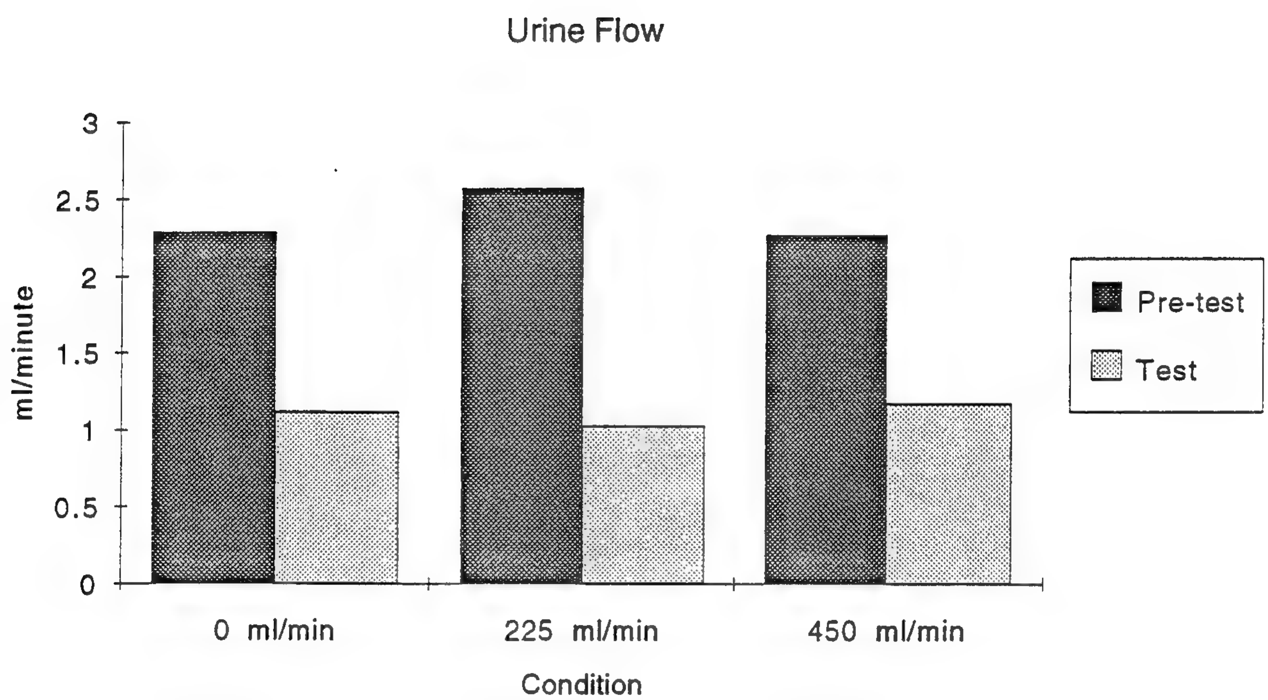

Respiration Rate
Mean of 6 Subjects
(5 pt. moving average)
Respiration Rate (breaths/min)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0
10
20
30
40
50
60
70
80
90
100
Time (minutes)
0 ml/min
225 ml/min
450 ml/min

FIGURE XIX.



Urine Flow
3
2.5
2
1.5
1
0.5
0
ml/minute
Pre-test
Test
0 ml/min
225 ml/min
450 ml/min
Condition

FIGURE XX.

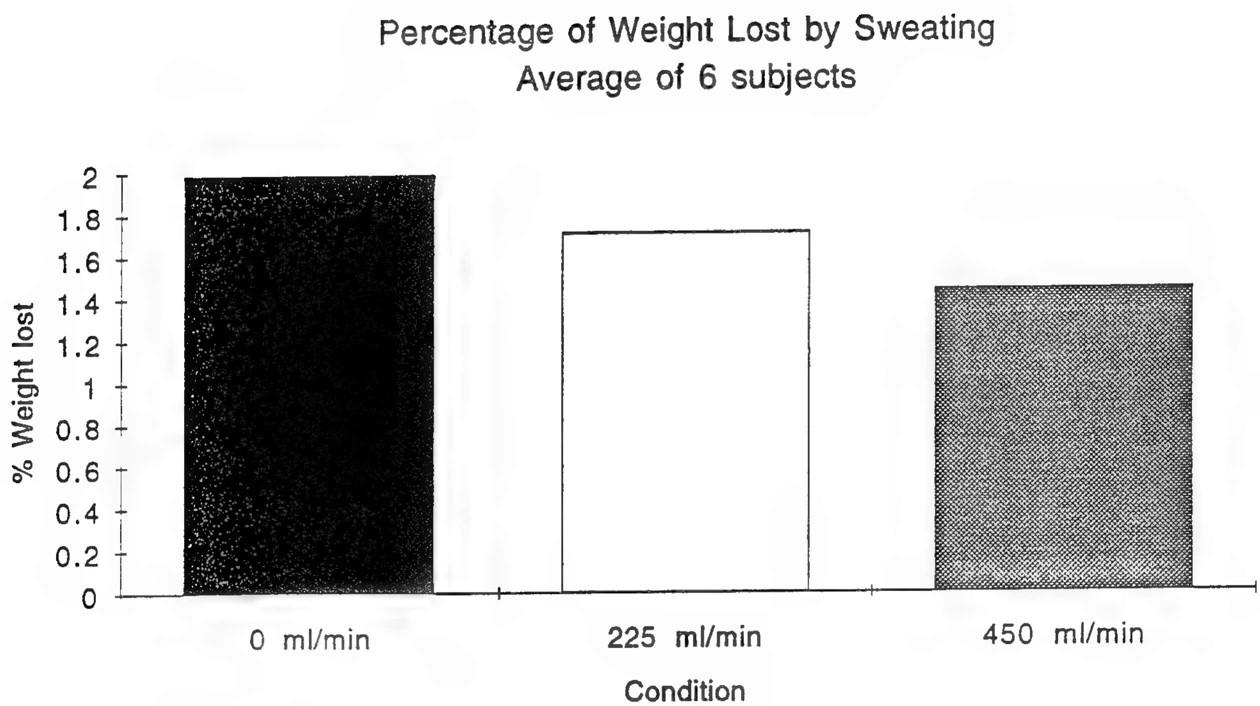

Percentage of Weight Lost by Sweating
Average of 6 subjects
% Weight lost
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0 ml/min
225 ml/min
450 ml/min
Condition

FIGURE XXI.

DISCUSSION

In order to evaluate the effectiveness of the cooling system, certain parameters were evaluated at four specific time points in the test protocol: (1) initial values, (2) at the end of the first 50 min of exercise, (3) at the end of the 10-min rest period just prior to the second 50 min of exercise, and (4) at the end of 90 min of exercise. The 90-min point was selected because at this time point none of the protocols had been terminated. The experimental protocol was designed to approximate a moderate stress level that would result in relatively slow changes in the parameters monitored, therefore it was felt appropriate to select fixed time points to evaluate changes during the experiments and to use these points for making comparisons between different conditions. Tables IIIa through IIIf present the following parameters: rectal, tympanic, thigh skin temperatures, heart rate, systolic blood pressure, diastolic blood pressure, mean blood pressure, and weight loss for each of the 6 subjects and for each of the three conditions. The data are presented as both raw values and as changes between specific time points in the protocols. Table IV contains the mean values of the 6 subjects for each parameter and condition.

To analyze the changes in measured parameters as a function of time, statistical analysis was done comparing each parameter at time points 0, 50, and 90 min. Of the parameters analyzed, rectal and tympanic temperatures and heart rate demonstrated the most consistent statistical differences. Table V summarizes the statistical analysis of changes in these parameters with respect to time. For rectal, tympanic temperatures, and heart rate, the 50 and 90 min values were significantly different from their initial values for all conditions. In the no cool condition the rectal temperature and heart rate showed a significant difference between the 50- and 90-min points, whereas the cooling conditions did not. This would suggest that the rate of rise in core temperature and heart rate was less in both cooling conditions, or there may be a temporary stabilization of these parameters during the second exercise period.

Table VI summarizes the statistical comparisons of the three conditions at the 50 and 90-min time points for rectal, tympanic temperatures, and heart rate. There is no significant difference between the moderate (225) and maximum (450) cooling conditions at either the 50- or 90-min time points. With respect to the comparison of the no cool to the moderate (225) cooling, cooling resulted in a significant depression of tympanic temperature at the 50- and 90-min time points and in heart rate at the 90-min time point. When maximum (450) cooling rate condition was compared to the no cooling condition, tympanic temperature was significantly lower at the 50-min time point and all three parameters were significantly lower at the 90-min time point.

SUMMARY

1. In both cooling conditions (moderate-225 and maximum-450) all subjects completed the 2-hr heat-exercise stress without exceeding either the core temperature or cardiovascular limits.
2. The use of microclimate cooling reduced body water loss due to sweating from 2% of the body weight to 1.4% of the body weight. This represents a 30% decrease in water loss with cooling during the heat-exercise exposure.
3. The use of microclimate cooling reduced the core temperature rise, measured by either rectal or tympanic temperatures, during the second hour of the heat-exercise stress.
4. The use of microclimate cooling significantly reduced cardiovascular stress, as estimated by increases in heart rate, during the second hours of the heat-exercise stress.

Table III - a.

Test Data for Condition:	0 ml/min		
Subject:	bs		
Duration of experiment (min):	110 min		
	Control	50	(end - 10) min
Heart Rate	108	140	168
Rectal	37.3	38	38.6
Tympanic	37.8	37.7	38.2
Chest	36.6	37.6	38.3
Thigh	35.1	36.8	37.3
Systolic	135	107	157
Diastolic	79	76	77
Mean BP	97.7	86.3	103.7
	Reason for stopping exp:		HR ext

	50-control	(end-10) - 60	(end-10)-cont
Δ HR	32	68	60
Δ Rectal	0.7	0.7	1.3
Δ Tympanic	-0.1	0.9	0.4
Δ Chest	1	0.9	1.7
Δ Thigh	1.7	0.7	2.2
	Control	Test	Control - test
Urine flow	1.36	0.65	0.71
Spec. Gravity	1.014	1.006	0.008
Proteins	-	-	
"Test" volume		72	
Δ weight	1.9 kg.		

Test Data for Condition:	225 ml/min		
Subject:	bs		
Duration of experiment (min):	115 min		
	Control	50	(end - 10) min
Heart Rate	98	110	122
Rectal	37	37.6	37.9
Tympanic	37.2	37.7	37.8
Chest	27	25	25.4
Thigh	33.3	36	36.2
Systolic	112	121	122
Diastolic	79	69	80
Mean BP	90.0	86.3	94.0
	Reason for stopping exp:		treadmill

	50-control	(end-10) - 60	(end-10)-cont
Δ HR	12	46	24
Δ Rectal	0.6	0.6	0.9
Δ Tympanic	0.5	0	0.6
Δ Chest	-2	-0.3	-1.6
Δ Thigh	2.7	-0.3	2.9
	Control	Test	Control - test
Urine flow	1.79	0.75	1.04
Spec. Gravity	1.003	1.01	-0.007
Proteins	-	-	
"Test" volume		86	
Δ weight	1.4 kg.		

Test Data for Condition:	450 ml/min		
Subject:	bs		
Duration of experiment (min):	120 min		
	Control	50	(end - 10) min
Heart Rate	63	132	120
Rectal	37.1	37.8	38.7
Tympanic	37	37.7	37.6
Chest	31.4	33.2	31.5
Thigh	35	35.7	35.7
Systolic	108	121	119
Diastolic	71	75	72
Mean BP	83.3	90.3	87.7
	Reason for stopping exp:		na

	50-control	(end-10) - 60	(end-10)-cont
Δ HR	69	30	57
Δ Rectal	0.7	1	1.6
Δ Tympanic	0.7	0	0.6
Δ Chest	1.8	-0.1	0.1
Δ Thigh	0.7	-0.3	0.7
	Control	Test	Control - test
Urine flow	1.1	0.63	0.47
Spec. Gravity	1.019	1.02	-0.001
Proteins	t	t	
"Test" volume		76	
Δ weight	1.5 kg.		

Table III - b.

Test Data for Condition: **0 ml/min**
Subject: db
Duration of experiment (min): 100 min

	Control	50	(end - 10) min
Heart Rate	84	132	144
Rectal	37.6	38.3	39.2
Tympanic	37.7	38.7	39.5
Chest	36.8	38.3	38.9
Thigh	34.6	37.5	38.1
Systolic	125	130	128
Diastolic	78	64	69
Mean BP	93.7	86.0	88.7
	Reason for stopping exp:		tymp

	50-control	(end-10) - 60	(end-10)-cont
Δ HR	48	44	60
Δ Rectal	0.7	0.9	1.6
Δ Tympanic	1	0.9	1.8
Δ Chest	1.5	1.2	2.1
Δ Thigh	2.9	0.4	3.5

	Control	Test	Control - test
Urine flow	6.85	0.68	6.17
Spec. Gravity	1.004	1.015	-0.011
Proteins	-	t	
"Test" volume		68	
Δ weight	1.4 kg.		

Test Data for Condition: **225 ml/min**
Subject: db
Duration of experiment (min): 120 min

	Control	50	(end - 10) min
Heart Rate	68	104	116
Rectal	37.5	37.9	38.3
Tympanic	36.9	37.9	39
Chest	34.5	37.3	37.5
Thigh	34.3	36.5	36.7
Systolic	114	141	116
Diastolic	71	82	63
Mean BP	85.3	101.7	80.7
	Reason for stopping exp:		na

	50-control	(end-10) - 60	(end-10)-cont
Δ HR	36	44	48
Δ Rectal	0.4	0.4	0.8
Δ Tympanic	1	1	2.1
Δ Chest	2.8	0.6	3
Δ Thigh	2.2	0.2	2.4

	Control	Test	Control - test
Urine flow	1.93	0.53	1.4
Spec. Gravity	1.011	1.015	-0.004
Proteins	-	t	
"Test" volume		64	
Δ weight	1.2 kg.		

Test Data for Condition: **450 ml/min**
Subject: db
Duration of experiment (min): 120 min

	Control	50	(end - 10) min
Heart Rate	65	100	108
Rectal	37.1	37.7	37.8
Tympanic	36.8	37.8	37.9
Chest	33.1	33	33.1
Thigh	33.7	36.9	37.1
Systolic	113	134	114
Diastolic	69	70	62
Mean BP	83.7	91.3	79.3
	Reason for stopping exp:		na

	50-control	(end-10) - 60	(end-10)-cont
Δ HR	35	38	43
Δ Rectal	0.6	0.5	0.7
Δ Tympanic	1	0.2	1.1
Δ Chest	-0.1	2.9	0
Δ Thigh	3.2	0.4	3.4

	Control	Test	Control - test
Urine flow	4.84	0.76	4.08
Spec. Gravity	1.005	1.01	-0.005
Proteins	-	t	
"Test" volume		91	
Δ weight	0.8 kg.		

Table III - c.

Test Data for Condition:	0 ml/min		
Subject:	ed		
Duration of experiment (min):	100 min		
	Control	50	(end - 10) min
Heart Rate	82	126	155
Rectal	37	37.6	38.3
Tympanic	36.9	38.4	39.1
Chest	36	36.2	37.3
Thigh	34.2	37.7	38.6
Systolic	132	126	146
Diastolic	69	76	61
Mean BP	90.0	92.7	89.3
	Reason for stopping exp:		tymp

	50-control	(end-10) - 60	(end-10)-cont
Δ HR	44	36	73
Δ Rectal	0.6	0.6	1.3
Δ Tympanic	1.5	0.4	2.2
Δ Chest	0.2	1.4	1.3
Δ Thigh	3.5	1.7	4.4
	Control	Test	Control - test
Urine flow	1.67	1.84	-0.17
Spec. Gravity	1.015	1.01	0.005
Proteins	-	-	
"Test" volume		184	
Δ weight	1.1 kg.		

Test Data for Condition:	225 ml/min		
Subject:	ed		
Duration of experiment (min):	120 min		
	Control	50	(end - 10) min
Heart Rate	82	124	116
Rectal	36.6	37.3	37.5
Tympanic	36.6	37.8	37.7
Chest	34.8	36.9	36.8
Thigh	*	*	*
Systolic	116	119	110
Diastolic	71	62	54
Mean BP	86.0	81.0	72.7
	Reason for stopping exp:		na

	50-control	(end-10) - 60	(end-10)-cont
Δ HR	42	32	34
Δ Rectal	0.7	0.2	0.9
Δ Tympanic	1.2	0.2	1.1
Δ Chest	2.1	0.2	2
Δ Thigh	*	*	*
	Control	Test	Control - test
Urine flow	8.13	3.07	5.06
Spec. Gravity	1.002	1.006	-0.004
Proteins	-	t	
"Test" volume		368	
Δ weight	1.4 kg.		

Test Data for Condition:	450 ml/min		
Subject:	ed		
Duration of experiment (min):	120 min		
	Control	50	(end - 10) min
Heart Rate	82	117	120
Rectal	37.1	37.8	38
Tympanic	37.2	37.8	38
Chest	35.3	36	37.1
Thigh	34.8	35.4	35.4
Systolic	126	128	126
Diastolic	71	55	112
Mean BP	89.3	79.3	116.7
	Reason for stopping exp:		na

	50-control	(end-10) - 60	(end-10)-cont
Δ HR	35	15	38
Δ Rectal	0.7	0.2	0.9
Δ Tympanic	0.6	0.3	0.8
Δ Chest	0.7	0.2	1.8
Δ Thigh	0.6	0.6	0.6
	Control	Test	Control - test
Urine flow	2.88	2.95	-0.07
Spec. Gravity	1.003	1.006	-0.003
Proteins	-	t	
"Test" volume		354	
Δ weight	1.0 kg.		

Table III - d.

Test Data for Condition:	0 ml/min		
Subject:	me		
Duration of experiment (min):	100 min		
	Control	50	(end - 10) min
Heart Rate	70	144	172
Rectal	37.2	37.6	38
Tympanic	37.3	37.8	38.4
Chest	35.2	36.9	37.7
Thigh	34.8	36.6	36.5
Systolic	133	131	141
Diastolic	73	68	70
Mean BP	93.0	89.0	93.7
	Reason for stopping exp:		HR acute

	50-control	(end-10) - 60	(end-10)-cont
Δ HR	74	44	102
Δ Rectal	0.4	0.3	0.8
Δ Tympanic	0.5	0.6	1.1
Δ Chest	1.7	0.6	2.5
Δ Thigh	1.8	-0.4	1.7
	Control	Test	Control - test
Urine flow	1.78	2.63	-0.85
Spec. Gravity	1.01	1.004	0.006
Proteins	-	-	
"Test" volume		263	
Δ weight	1.8 kg.		

Test Data for Condition:	225 ml/min		
Subject:	me		
Duration of experiment (min):	120 min		
	Control	50	(end - 10) min
Heart Rate	75	128	112
Rectal	37.2	37.4	37.5
Tympanic	37.1	37.6	37.9
Chest	35	31.1	34.5
Thigh	34.1	36	33.3
Systolic	121	139	134
Diastolic	62	72	62
Mean BP	81.7	94.3	86.0
	Reason for stopping exp:		na

	50-control	(end-10) - 60	(end-10)-cont
Δ HR	53	44	37
Δ Rectal	0.2	0.3	0.3
Δ Tympanic	0.5	0.6	0.8
Δ Chest	-3.9	5.5	-0.5
Δ Thigh	1.9	-2	-0.8
	Control	Test	Control - test
Urine flow	0.75	0.46	0.29
Spec. Gravity	-	1.026	-1.026
Proteins	-	2+	
"Test" volume		55	
Δ weight	1.1 kg.		

Test Data for Condition:	450 ml/min		
Subject:	me		
Duration of experiment (min):	120 min		
	Control	50	(end - 10) min
Heart Rate	78	112	128
Rectal	37.3	37.2	37.4
Tympanic	37	37.4	37.4
Chest	28.6	22.5	23.6
Thigh	33.6	35.4	35.5
Systolic	121	140	133
Diastolic	71	74	75
Mean BP	87.7	96.0	94.3
Reason for stopping exp:	na		

	50-control	(end-10) - 60	(end-10)-cont
Δ HR	34	48	50
Δ Rectal	-0.1	0.4	0.1
Δ Tympanic	0.4	0.2	0.4
Δ Chest	-6.1	0.2	-5
Δ Thigh	1.8	0.5	1.9
	Control	Test	Control - test
Urine flow	1.12	*	*
Spec. Gravity	1.01	1.009	0.001
Proteins	-	!	
"Test" volume		*	
Δ weight	1.1 kg.		

Table III - e.

Test Data for Condition:	0 ml/min		
Subject:	sh		
Duration of experiment (min):	120 min		
	Control	50	(end - 10) min
Heart Rate	84	120	150
Rectal	37.4	37.6	38.6
Tympanic	37.5	37.9	38.8
Chest	35.9	37.5	38.4
Thigh	34	35.2	36.9
Systolic	130	134	133
Diastolic	73	64	55
Mean BP	92.0	87.3	81.0
Reason for stopping exp:	na		

	50-control	(end-10) - 60	(end-10)-cont
Δ HR	36	66	66
Δ Rectal	0.2	0.9	1.2
Δ Tympanic	0.4	0.8	1.3
Δ Chest	1.6	1	2.5
Δ Thigh	1.2	2.1	2.9
	Control	Test	Control - test
Urine flow	1.36	0.53	0.83
Spec. Gravity	1.014	1.019	-0.005
Proteins	-	t	
"Test" volume		64	
Δ weight	1.6 kg.		

Test Data for Condition:	225 ml/min		
Subject:	sh		
Duration of experiment (min):	120 min		
	Control	50	(end - 10) min
Heart Rate	84	122	140
Rectal	37.5	37.7	38
Tympanic	37.6	37.8	38.2
Chest	35.8	36.7	36.7
Thigh	34.5	36.4	36.4
Systolic	128	120	126
Diastolic	71	58	59
Mean BP	90.0	78.7	81.3
	Reason for stopping exp:		na

	50-control	(end-10) - 60	(end-10)-cont
Δ HR	38	20	56
Δ Rectal	0.2	0.2	0.5
Δ Tympanic	0.2	0.4	0.6
Δ Chest	0.9	-0.3	0.9
Δ Thigh	1.9	0.6	1.9
	Control	Test	Control - test
Urine flow	0.86	0.36	0.5
Spec. Gravity	1.023	1.025	-0.002
Proteins	-	t	
"Test" volume		43	
Δ weight	1.8 kg.		

Test Data for Condition:	450 ml/min		
Subject:	sh		
Duration of experiment (min):	120 min		
	Control	50	(end - 10) min
Heart Rate	90	130	130
Rectal	37.5	37.8	38.2
Tympanic	37.3	37.4	37.9
Chest	34.5	36.5	36.8
Thigh	34.1	36	36.9
Systolic	136	113	128
Diastolic	82	61	67
Mean BP	100.0	78.3	87.3
	Reason for stopping exp:		na

	50-control	(end-10) - 60	(end-10)-cont
Δ HR	40	30	40
Δ Rectal	0.3	0.4	0.7
Δ Tympanic	0.1	0.6	0.6
Δ Chest	2	1.3	2.3
Δ Thigh	1.9	1.1	2.8
	Control	Test	Control - test
Urine flow	2.51	0.91	1.6
Spec. Gravity	1.008	1.01	-0.002
Proteins	-	-	
"Test" volume		109	
Δ weight	1.2 kg.		

Table III - f.

Test Data for Condition: **0 ml/min**
Subject: sp
Duration of experiment (min): 110 min

	Control	50	(end - 10) min
Heart Rate	88	140	170
Rectal	36.9	38.2	38.8
Tympanic	37	38.9	40.3
Chest	35.9	37.2	38.1
Thigh	34.1	36.9	38.2
Systolic	111	122	122
Diastolic	62	61	65
Mean BP	78.3	81.3	84.0
Reason for stopping exp:			tymp

	50-control	(end-10) - 60	(end-10)-cont
Δ HR	52	62	82
Δ Rectal	1.3	0.5	1.9
Δ Tympanic	1.9	1.7	3.3
Δ Chest	1.3	0.5	2.2
Δ Thigh	2.8	1.6	4.1
	Control	Test	Control - test
Urine flow	0.7	0.39	0.31
Spec. Gravity	1.015	1.02	-0.005
Proteins	-	t	
"Test" volume		43	
Δ weight	1.6 kg.		

Test Data for Condition: **225 ml/min**
Subject: sp
Duration of experiment (min): 120 min

	Control	50	(end - 10) min
Heart Rate	80	130	140
Rectal	36.8	38	38.4
Tympanic	36.6	37.4	37.7
Chest	35.6	35.4	35.6
Thigh	34.1	36.6	36.7
Systolic	123	142	125
Diastolic	70	83	74
Mean BP	87.7	102.7	91.0
Reason for stopping exp:		na	

	50-control	(end-10) - 60	(end-10)-cont
Δ HR	50	52	60
Δ Rectal	1.2	0.6	1.6
Δ Tympanic	0.8	0.6	1.1
Δ Chest	-0.2	-0.1	0
Δ Thigh	2.5	-0.5	2.6
	Control	Test	Control - test
Urine flow	1.96	1	0.96
Spec. Gravity	1.012	1.017	-0.005
Proteins	-	t	
"Test" volume		120	
Δ weight	1.2 kg.		

Test Data for Condition: **450 ml/min**
Subject: sp
Duration of experiment (min): 120 min

	Control	50	(end - 10) min
Heart Rate	76	120	125
Rectal	37.2	38.2	38.4
Tympanic	36.7	38	38.4
Chest	35.1	22.3	23.7
Thigh	34.2	36.4	36.9
Systolic	128	144	141
Diastolic	78	86	82
Mean BP	94.7	105.3	101.7
Reason for stopping exp:		na	

	50-control	(end-10) - 60	(end-10)-cont
Δ HR	44	25	49
Δ Rectal	1	0.2	1.2
Δ Tympanic	1.3	0.8	1.7
Δ Chest	-12.8	1.1	-11.4
Δ Thigh	2.2	0.8	2.7
	Control	Test	Control - test
Urine flow	1.16	0.61	0.55
Spec. Gravity	1.015	1.016	-0.001
Proteins	t	t.	
"Test" volume		73	
Δ weight	1.0 kg.		

Table IV.

Test Data for Condition: **0 ml/min**
Subject: Mean of 6

	Control	50	(end - 10) min
Heart Rate	86.0	133.7	159.8
Rectal	37.2	37.9	38.6
Tympanic	37.4	38.2	39.1
Chest	36.1	37.3	38.1
Thigh	34.5	36.8	37.6
Systolic	127.7	125.0	137.8
Diastolic	72.3	68.2	66.2
Mean BP	90.8	87.1	90.1

	50-control	(end-10) - 60	(end-10)-cont
Δ HR	47.7	53.3	73.8
Δ Rectal	0.7	0.7	1.4
Δ Tympanic	0.9	0.9	1.7
Δ Chest	1.2	0.9	2.1
Δ Thigh	2.3	1.0	3.1

	Control	Test	Control - test
Urine flow	2.3	1.1	1.2
Spec. Gravity	1.0120	1.0123	0.0
"Test" volume		115.5	
Δ weight	1.6		

Test Data for Condition: **225 ml/min**
Subject: Mean of 6

	Control	50	(end - 10) min
Heart Rate	81.2	119.7	124.3
Rectal	37.1	37.7	37.9
Tympanic	37.0	37.7	38.1
Chest	33.8	33.7	34.4
Thigh	34.1	36.3	35.9
Systolic	119.0	130.3	122.2
Diastolic	70.7	71.0	65.3
Mean BP	86.8	90.8	84.3

	50-control	(end-10) - 60	(end-10)-cont
Δ HR	38.5	39.7	43.2
Δ Rectal	0.5	0.4	0.8
Δ Tympanic	0.7	0.5	1.1
Δ Chest	0.0	0.9	0.6
Δ Thigh	2.2	-0.4	1.8

	Control	Test	Control - test
Urine flow	2.6	1.0	1.5
Spec. Gravity	1.0102	1.0165	-0.2
Δ weight	1.3		

Test Data for Condition: **450 ml/min**
Subject: Mean of 6

	Control	50	(end - 10) min
Heart Rate	75.7	118.5	121.8
Rectal	37.2	37.8	38.1
Tympanic	37.0	37.7	37.9
Chest	33.0	30.6	31.0
Thigh	34.2	36.0	36.3
Systolic	122.0	130.0	126.8
Diastolic	73.7	70.2	78.3
Mean BP	89.8	90.1	94.5

	50-control	(end-10) - 60	(end-10)-cont
Δ HR	42.8	31.0	46.2
Δ Rectal	0.5	0.5	0.9
Δ Tympanic	0.7	0.3	0.9
Δ Chest	-2.4	0.9	-2.0
Δ Thigh	1.7	0.5	2.0

	Control	Test	Control - test
Urine flow	2.3	1.2	1.3
Spec. Gravity	1.0100	1.0118	0.0
Δ weight	1.1		

Table V.

Statistical analysis of rectal temperature, tympanic temperature and heart rate as a function of time-50 and 90 minute points. An x indicates that the 50 and/or 90 minute point was significantly different ($p < 0.05$) from the parameter measured at time = 0 minutes. A + indicates that the 90 minute value was significantly different from the 50 minute value.

Condition	Parameter	50 minutes	90 minutes
no cool	Rectal Temp	x	x +
cooling 225	Rectal Temp	x	x
cooling 450	Rectal Temp	x	x
no cool	Tympanic Temp	x	x
cooling 225	Tympanic Temp	x	x
cooling 450	Tympanic Temp	x	x
no cool	Heart Rate	x	x +
cooling 225	Heart Rate	x	x
cooling 450	Heart Rate	x	x

Table VI.

Statistical analysis of rectal temperature, tympanic temperature and heart rate as a function of time; 50 and 90 minute points; and condition comparison. An S indicates that the comparisons of conditions were significantly different ($p < 0.05$) at the indicated time point. An NS indicates that the comparison was not significantly different at the indicated time point.

		CONDITION COMPARISON		
		0 vs. 225	**0 vs. 450**	**225 vs.450**
Time	**Parameter**			
50 min.	Rectal Temp	NS	NS	NS
90 min.	Rectal Temp	NS	S	NS
50 min.	Tympanic Temp	S	S	NS
90 min.	Tympanic Temp	S	S	NS
50 min.	Heart Rate	NS	NS	NS
90 min.	Heart Rate	S	S	NS

Recommendations for Further Development and Evaluations:

The results presented in this report support the use of microclimate cooling as beneficial in situations of heat and exercise stress. The following comments should act as a guide for further work with this system.

1. The cap cooling apparatus presents a problem in that its circulation can be impeded by gas mask adjustments. Consider removing the cap and reevaluating the system with just the vest cooling or with the cap over the gas mask straps. Without the cap, the system would be much easier to handle in field applications.

2. The delivery of cooling fluid at 250 ml/min was almost as effective as 450 ml/min. Consider reevaluation of the system at either lower flow rates of cooling fluid or higher temperatures of input fluid. The problem to be addressed here is at what point the vasoconstriction induced by the cooling system impedes heat flow out of the body core. This study could better optimize cooling and minimize energy expenditure of the equipment.

3. Expand evaluation of the limits of the system. The data presented here indicates that the system as tested will allow an individual to walk at 3 mph, 2% grade for 2 hr with minimal rise in core temperature and heart rate. This is a significant improvement over the no cooling condition. The question is, how far can you push this system? After questions 1 and 2 are answered, the protocol should be redesigned to increase the stress to the subject. This could be done by either an increase in ambient temperature or increase in exercise load. Both possibilities should be considered. The specific experimental design would depend upon the primary application of the data.

4. Would it be beneficial to add a method to hydrate the subject during the heat exercise stress? Even with the maximum cooling activated, the subjects in these experiments lost 0.7% of their body weight per hour via sweat and respiratory water loss.

5. The design of the system used here employed a long umbilicus to supply the cooling fluid to the vest-cap system. Since the inflow/outflow tubes are not insulated from each other, the possibility of countercurrent heat exchange exists. This possibility should be investigated and corrected if the magnitude of the problem is large enough.

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13. ABSTRACT *(Maximum 200 words)*
The threat of chemical warfare associated with the war in the Persian Gulf revealed that insufficient information is available regarding military personnel who can be exposed to both a hot environment and chemical/biological attack. The chemical, biological, radiological (CBR) protective ensembles worn under threat of chemical/biological attack prevent noxious agents from reaching the skin; however heat metabolically generated or gained from the environment is prevented from dissipating. Thus in this scenario, microclimate cooling may be essential to prevent heat injury. This study was designed to determine the efficiency of a microclimate cooling system (MCS) in preventing heat strain in six unacclimated males who performed moderate exercise (walking at 3 mph, 2% grade), in a hot environment (100°F), while encapsulated in a chemical protective overgarment with either no cooling (NC), intermediate cooling (IC) (coolant flow rate = 225 ml/min), or maximal cooling (MC) (coolant flow rate = 450 ml/min). Heart rate (HR), core temperature (T_{re}), and stay time were measured as indices of heat strain. There was no difference in HR or T_{re} at 50 min and 90 min between the IC and MC conditions, and all participants reached the maximal time limit (120 min) in both conditions. HR and T_{re} were lower in the IC and MC conditions than the NC condition at min 90 and stay time was longer in IC and MC than NC. The use of this MCS reduced cardiovascular stress, as estimated by increases in HR and reduced thermal stress, as estimated by increases in T_{re}; however, the higher coolant flow rate conferred no thermoregulatory advantage over the lower flow rate.

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